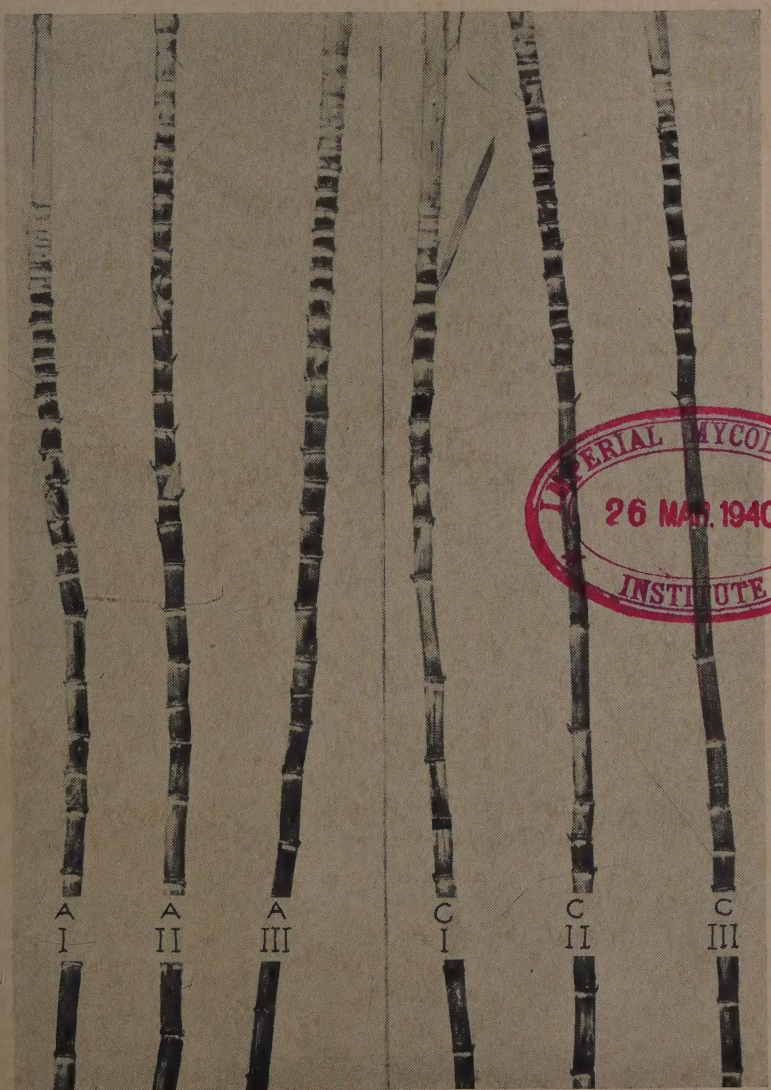
VOLUME XLIII NUMBER 3

THE HAWAIIAN PLANTERS' RECORD



The greatly increased internode elongation of the "C" over the "A" stalks was an effect of intermittently reduced periods of direct sunlight during the "boom" stage of growth.

THIRD QUARTER 1939

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THE HAWAIIAN
PLANTERS' RECORD

Vol. XLIII THIRD QUARTER 1939 No. 3

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Nitrogen in the Cane Leaf:

A method is described which is, at present, under development as a means of estimating the nitrogen requirement of sugar cane. The procedure of study, first proposed and inaugurated by H. P. Agee, includes an R.C.M. analysis of specific cane leaf tissue obtained by a ticket punch. A relationship appears to exist between the nitrogen content of the leaf tissue taken from a definite region on the cane stalk, and growth of the plant. The results of this study have contributed to improvement of experimental technic which, it is hoped, may eventually lead to the establishment of a practical control in nitrogen fertilization of sugar cane. The method is based upon making periodic ticket-punch collections of leaf specimens in the field, obtaining their total nitrogen content by R.C.M. analysis and estimating the needs of the crop for nitrogen by interpreting the data with respect to the *sufficiency* of the nutrient at different ages of growth. Potential application in practice of the system is discussed, aided by data presented graphically.

Dead Cane at Harvest:

The factors causing cane to die prior to harvest are at times obvious but there are many instances where the causal factor or factors are not understood. In this paper an attempt has been made to list and briefly discuss the more common factors responsible for dead cane at harvest.

The Effects of Oven Drying and Air Drying on the Available Nitrogen Content of Soils:

A resume is presented of a study made to determine the extent and character of changes taking place in the concentration of *available* soil nitrogen as a result of natural or artificial drying of the soil preparatory to chemical analysis.

A rapid chemical method is described for the determination of *total available* nitrogen in the freshly collected, moist soil specimen.

Sunlight-Nitrogen Relationships:

Interesting evidence is presented of the separate effects upon cane growth and quality from variations in periods of exposure to direct sunlight and from different amounts of nitrogen, but no significant interaction between these two factors was brought out in this first of a series of skirmish tests concerned with these issues.

Nitrogen in the Cane Leaf

By Q. H. Yuen and Francis E. Hance

A study of some relationships existing between the total nitrogen of a specific region of the cane plant, considering associated meteorological influences, and with related factors probably affecting crop growth, fertilizer requirements, maturing and, as ripening sets in, with expected quality of crusher juice.

The determination of the "nitrogen index" of a field of cane by an organized collection and R.C.M. analysis of ticket-punch leaf specimens secured at monthly intervals currently with the development of the crop.

An attempted development of a plantation field-scale nitrogen fertilizer control (potash and phosphate assumed not limiting factors).

Cane tonnage in sugar production in Hawaii has increased considerably during the past twenty years. However, the number of tons of cane required to produce a ton of sugar has also increased and hence economy of production has fallen off. Employment of new varieties, improved cultural practices and liberal use of fertilizers have, of course, been responsible to a large extent for advances made in increased tonnage and at times for improvement in yield.

From the standpoint of an efficient fertilizer practice, nitrogen applied in excess of crop requirement has been considered by many as having favored cane tonnage at the expense of cane quality. The effect of nitrogen on the sucrose content of sugar cane grown under field conditions was made a subject of thorough investigation by Alexander (2), Verret (16) and Borden (3). In general, their conclusions coincide in that increasing increments of nitrogen applied above a certain minimum optimum have a depressing effect upon quality of juice.

The subject of control in nitrogen fertilization is, therefore, one of importance both from the standpoint of cultural practice and from related economic aspects.

Control of crop fertilization may be based on field experiment, laboratory cultural experiment, soil analysis, plant analysis, or by rule of thumb—the expedient commonly resorted to in nitrogen fertilization. However, limitations are inherent in all such procedures, but a degree of reliability may be realized by combining a number of them or by a correlation study of the whole series of data. Another modification of crop fertilization control embraces an interrelated soil and plant material analysis. Such a method was proposed in a paper by Lundegärdh (11).

A modicum of success in the control of crop fertilization by soil analysis has been achieved for phosphate and potash on Hawaiian sugar plantations. In the case of nitrogen, only partial control can be exercised by this means due to the characteristic behavior of nitrogen in the soil under Hawaiian conditions. This subject has been discussed by Yuen and Borden (17) in a recent publication. They point out that a determination of the *available* nitrogen in the soil will only indicate soil fertility for this nutrient at the moment of collection and that nitrogen applied to a

growing crop will not remain in the soil for any appreciable period of time due to rapid absorption by the crop—an established fact—and due also, it appears, to shifty availability occasioned by chemical reaction, microbiological activity, or loss by leaching. Dean (8) and his associates have shown that ammonia and nitrate nitrogen, available to plant life, are produced under field conditions from the organic nitrogen reserves of the soil. Pending the completion of Dean's researches and the development of R.C.M. procedures for evaluating these factors, chemical analysis of soils for the estimation of the crop requirement or its available supply of nitrogen, we believe, can only be partially sufficient. Incidentally, the researches of Dean and his coworkers have resulted in the development of a method to determine the quantity of "mineralizable nitrogen," as they describe it, in a soil by subjecting the soil to controlled incubation under laboratory conditions and thereafter determining the amount of available nitrogen formed after a stated period.

If immediate control in nitrogen fertilization is to be attempted in the cane field, it appears that soil analysis should be supplemented by analysis of the plant itself, provided reliability of the procedure can be secured. Another factor which enters into a consideration of nitrogen nutrition is the effect of weather on the behavior of this nutrient in the plant and in the soil which supports it. A discussion of the relationship of climate to sugar production in Hawaii has been published by Das (4, 5). From these and later studies (6) the inference may be gathered that climatic conditions of temperature and sunlight play important roles in the growth processes of the plant, which in turn may affect the nitrogen requirement of the crop. With favorable weather conditions, large applications of nitrogen may be utilized by cane, apparently, and heavier tonnages secured without undue detrimental effects upon the quality of crusher juice. During periods or cycles of unfavorable growing weather, less nitrogen may be supplied to the crop if the detrimental factor of luxury consumption and consequent effects upon ripening and juice quality are to be avoided. The nitrogen requirement of sugar cane, therefore, appears to be one that is variable. Any control of this requirement that would prove satisfactory should be one that reflects or indicates such variability. Attention was therefore directed to the cane plant itself. Pursuit of this objective has engaged the attention of Agee for years. An exposition of the logic which justifies this research appears in the text of his paper, "The Sugar Planter Looks at Botany" published in 1932 (1).

In the summer of 1938 a definite field study of nitrogen in the cane plant was inaugurated by Agee at Waialua Agricultural Company, Ltd., and Ewa Plantation Company on the Island of Oahu. Cooperation in this study was contributed by several members of the plantation and Experiment Station staffs.

Efforts to locate distinctive zones in the cane plant, the analysis of which might yield information on its nutrient requirement, formed the early objective of the study. Various methods and procedures were developed as aids in this search, among which was a rapid chemical method for the analysis of leaf specimens to be obtained by ticket-punch procedure (10). Earlier studies by Q. H. Yuen and L. E. Davis, chemistry department of this Experiment Station, gave indications which suggested the feasibility of investigating the leaf-punch technic of sampling the growing plant. Further and more extensive field studies were undertaken. From results of these investigations, a standardized sampling procedure for an organized

foliar study of field canes was developed and the original rapid chemical method of analysis was modified to determine the total nitrogen content of the specimens on a moisture-free basis. The standardized procedure, as currently employed (April 1939) for leaf-punch collections, and the rapid chemical method of nitrogen determination will now be described.

Briefly stated, the samples are obtained with a ticket punch from localized areas of a definite group of leaves of a stalk of sugar cane. The punch cuts a disk 5 mm. in diameter. The leaf specimens are oven dried and analyzed for total nitrogen. The analytical procedure consists essentially of digesting the sample in a semi-micro Kjeldahl flask, using potassium sulfate and sulfuric acid containing a selenium catalyst. The sample, after digestion, is cooled and diluted with water. Strong alkali is added and the liberated ammonia is distilled into a water-jacketed absorption tube containing dilute sulfuric acid. After distillation and cooling, the solution containing the absorbed ammonia is made to a definite volume. Aliquots are taken for the colorimetric determination of nitrogen, using a specially prepared Nessler reagent with standard color solutions.

The procedure in detail follows:

1. Obtain samples in the field from growing cane.

2. Sample the leaves of the second, third and fourth "dewlap" (ligule) attachments on each stalk. The numbering starts from the top, counting the first *visible* dewlap nearest to the spindle as one. Punch two disks from each leaf at a point about midway from tip to base and about midway from margin to midrib, punching either or both blades.

3. Sample 10 stalks, obtaining 60 disks, or between 0.04 to 0.1 gram of dry tissue.

4. Transfer disks to a small tin box and cover securely.

5. Remove cover and dry in electric oven at 100°C. for 3 hours, or at 80°C. for 5 hours (or overnight). (Cover and receptacle may be nested.) When dry, remove cans from oven; replace covers. Place cans in a desiccator and cool for 15 minutes, or longer. Obtain dry weight of sample by transferring it to tared scoop and weighing on analytical balance. Record the dry weight.

6. Transfer the disks to a Kjeldahl flask of 300-ml. capacity.

7. A porous granule (about the size of half a corn grain) is dropped into the flask. About 0.3 gram (approximately ⅓ small hornspoonful) of special grade powdered potassium sulfate is added. Using a special pipette, 4 ml. of Reagent 15 Total N (sulfuric acid containing selenium) are transferred into the flask. The flask is rotated until every leaf disk is coated with the acid. The flask is then placed on a precision heater which has been preheated for at least 5 minutes and the digestion is thus continued for 30 minutes.

After this digestion period the flask is removed from the heater and cooled. One hundred ml. Reagent 18 Total N (distilled water) are then added, washing down the neck of the flask in the process. Fifteen ml. of Reagent 16 Total N (dilute sulfuric acid) are transferred to a calibrated test tube (200 x 29 mm.). The test tube is then immersed in a wide-mouth 500-ml. flask of water. The apparatus for distillation is set up. (For further description of the analytical procedure and reagents consult the paper (9) on rapid chemical method for the determination of total nitrogen in cane juice.) Add 20 ml. Reagent 17 Total N (strong alkali) to the Kjeldahl

flask and immediately connect with distillation assembly. Continue distillation until liquid in test tube reaches the calibrated mark and then remove from distillation apparatus.

8. The distillate, after cooling, is made up to 50-ml. volume with Reagent 18 Total N and mixed.

(*a*). In general, a mixture of 1 ml. distillate plus 5 ml. of Reagent 18 Total N and a 0.50-ml. distillate plus 5-ml. Reagent 18 Total N mixture will cover the range of nitrogen found in the sample. However, the table of readings to follow will cover any extremes, provided approximately 60-disk samples are taken.

9. (*a*). Using a special 1-ml. (calibrated to 0.1 ml.) Mohr pipette, transfer 1-ml. aliquots of the distillate to each of two comparison vials. Add 5 ml. Reagent 18 Total N with a special 5-ml. Mohr pipette. Add 1 ml. Reagent 6 N to each tube. Stopper and let stand 1 minute; mix if necessary. Then compare with color standards on the illuminator.

(*b*). Repeat procedure with another set of two vials, but use a 0.50-ml. aliquot of the distillate plus 5 ml. of Reagent 18 Total N.

(*c*). When proficiency in reading and matching color standards has been attained, the two different proportional mixtures may be made up at one time, developed, allowed to stand the 1-minute interval and then read.

(*d*). The other dilutions listed in the Table of Readings (0.25 ml. distillate plus 5 ml. Reagent 18 Total N and 1.5 ml. distillate plus 4.5 ml. Reagent 18 Total N) are only to be used when the 1-ml. and 0.5 ml. aliquots are unsatisfactory because of a too light or too dark color development. Standard tubes which give most satisfactory results are those between 3 and 6, inclusive.

10. Refer to the Table of Readings (Table I) for data on the calculation of the Percentage of Nitrogen in Leaf-Punch Samples. (The fractions between standard numbers of the table refer to the position of the unknown to its approximate matching between two adjacent standards.)

11. Refer to the Table of Factors for Dry Weight (Table II).

12. Factor times Reading = per cent Total N (dry basis). The average of the two readings multiplied by the Factor for Dry Weight will give the result for the analysis of the sample.

TABLE I

TABLE OF READINGS FOR NITROGEN DETERMINATION IN LEAF-PUNCH SAMPLES WHERE ENTIRE SAMPLE IS DISTILLED

(Dilutions below refer to Treatment of Distillate)

Standard No.	Dilution			
	1 ml. + 5	0.50 ml. + 5	0.25 ml. + 5	1.5 ml. + 4.5
1	0.012	0.022	0.042	0.008
.25	0.018	0.033	0.063	0.012
.50	0.024	0.044	0.084	0.016
.75	0.030	0.055	0.105	0.020
2	0.036	0.066	0.126	0.024
.25	0.042	0.077	0.147	0.028
.50	0.048	0.088	0.168	0.032
.75	0.054	0.099	0.189	0.036
3	0.060	0.110	0.210	0.040
.25	0.066	0.121	0.231	0.044
.50	0.072	0.132	0.252	0.048
.75	0.078	0.143	0.273	0.052
4	0.084	0.154	0.294	0.056
.25	0.090	0.165	0.315	0.060
.50	0.096	0.176	0.336	0.064
.75	0.102	0.187	0.357	0.068
5	0.108	0.198	0.378	0.072
.25	0.117	0.215	0.410	0.078
.50	0.126	0.231	0.442	0.084
.75	0.135	0.248	0.473	0.090
6	0.144	0.264	0.504	0.096
.25	0.153	0.281	0.536	0.102
.50	0.162	0.297	0.567	0.108
.75	0.171	0.314	0.598	0.114
7	0.180	0.330	0.630	0.120
.25	0.195	0.358	0.682	0.130
.50	0.210	0.385	0.735	0.140
.75	0.225	0.413	0.788	0.150
8	0.240	0.440	0.840	0.160

The above data are merely readings. To obtain the per cent total nitrogen (dry basis) in the sample, multiply READING by FACTOR FOR DRY WEIGHT.

READING × FACTOR = % Total N (dry basis)

TABLE II

TABLE OF FACTORS FOR DRY WEIGHT

The following factors are obtained by the formula:

$$\text{Factor (F)} = \frac{1}{\text{Dry weight of sample}}$$

Dry weight	Factor	Dry weight	Factor	Dry weight	Factor
0.040	25.0	0.060	16.7	0.080	12.5
0.041	24.4	0.061	16.4	0.081	12.3
0.042	23.8	0.062	16.1	0.082	12.2
0.043	23.2	0.063	15.9	0.083	12.0
0.044	22.7	0.064	15.6	0.084	11.9
0.045	22.2	0.065	15.4	0.085	11.8
0.046	21.7	0.066	15.1	0.086	11.6
0.047	21.2	0.067	14.9	0.087	11.5
0.048	20.8	0.068	14.7	0.088	11.4
0.049	20.4	0.069	14.5	0.089	11.2
0.050	20.0	0.070	14.3	0.090	11.1
0.051	19.6	0.071	14.1	0.091	11.0
0.052	19.2	0.072	13.9	0.092	10.9
0.053	18.9	0.073	13.7	0.093	10.8
0.054	18.5	0.074	13.5	0.094	10.6
0.055	18.2	0.075	13.3	0.095	10.5
0.056	17.8	0.076	13.2	0.096	10.4
0.057	17.5	0.077	13.0	0.097	10.3
0.058	17.2	0.078	12.8	0.098	10.2
0.059	16.9	0.079	12.6	0.099	10.1
0.060	16.7	0.080	12.5	0.100	10.0

Example:

(*a*) Dry weight of sample = 0.0812 gram

(*b*) Distillate analysis, Reading:

Dilution 1 and 5 = 0.180 Reading

Dilution ½ and 5 = 0.176 Reading

(*c*) Referring to Table of Factors for Dry Weight,

0.081 gram, Factor = 12.3

(*d*) Per cent total N = Factor times Reading

1 ml.+5 ml. dilution—12.3×0.180 = 2.21% T.N.

0.5 ml.+5 ml. dilution—12.3×0.176 = 2.16% T.N. } 2.19%

(*e*) or averaging the two readings:

0.180
0.176 } 0.178 (average reading)

and multiplying by Factor:

0.178×12.3 = 2.19% (result for the sample).

Discussion on the Field Sampling Procedure:

The procedure is based on sampling a definite grouping of leaves of the plant, but with random selection of stalks. In general, the object consists in obtaining a representative sample of cane growing in a field. In a stand of cane there may exist different orders of stalks, including tasseled and untasseled canes. Experience thus far has indicated that for consistency of results only the untasseled cane should be sampled. In selecting stalks for sampling, as much of the primary growth is included as may be consistent with the principle of random selection.

To insure reliability of results two composite samples are obtained from each field. Two sampling stations are thus established per field, each station comprising an area of about 25 feet square (25′×25′). Sixty leaf-punch disks constitute a sample. Two disks are taken from each leaf in a region located about halfway along the blade and about one-half the distance between the midrib and the outer edge of the leaf. The two disks may be spaced about an inch apart along the blade. The critical sampling zone comprises that portion of the leaf system representing the leaves attached to the second, third and fourth visible dewlaps (ligules), counting from the top of the plant. These three designated leaves appear to comprise that portion of the plant which will yield reliable information concerning the "nitrogen index." (The nitrogen content percentage of the specimen has been termed the "nitrogen index" by Mr. Agee.)

Sampling may start with cane about three months of age. For young cane, not yet head high (less than 6 feet from base to top of foliage) only the second leaf is punched. As the plant grows, the third and fourth dewlap leaves are included. The full complement of second, third and fourth dewlap leaves may be sampled generally after the cane has reached or exceeded the above designated height. When the full complement of leaves comprises the material to be sampled, ten stalks are selected for the purpose in each station. For young cane, a sufficient number of stalks are selected to insure a 60-disk sample.

Where it is desired to obtain leaf specimens before the plant reaches an age of three months, cane growing not longer than a period of two months may be sampled. In such a case only the first dewlap leaf should be punched and this obvious deviation from the regular sampling order should be recorded with the analytical data accruing from the analysis.

Accuracy and Precision of Analytical Method:

Accuracy: In the regular laboratory method for analyzing plant material, the sample used in analysis ranges from one to five grams dry matter. The macro-Kjeldahl procedure is used and the resulting ammoniacal distillate is titrated with standard acid. In the rapid chemical method only approximately 0.060 to 0.080 gram of dry matter is used for each determination. The resulting distillate is analyzed with a colorimetric procedure. The final concentration of the distillate used in colorimetric analysis ranges from 0.4 to 8 parts-per-million nitrogen so that the dilution factor is exceedingly large. In spite of the differences in quantities of sample and methods of analysis, the accuracy of the rapid method is extremely close in comparison with the macro method. For leaf-punch analysis the usual range of nitrogen content is between one and three per cent on the dry-weight basis. The accuracy for this type of analysis is found to be within at least 90 per cent of the regular laboratory method. It has been found that for cane juice analysis and certain biological solutions where the composition is between 0.010 and 0.200 per cent of total nitrogen the results obtained by the two methods are practically identical.

Precision: In an organized nitrogen study of the sugar cane leaf system, the data obtained are examined from the standpoint of time or age relationship. The precision of the method and the agreement between results of duplicate analysis become increasingly important. The significance of the difference between nitrogen

indices obtained during the growth period of the crop is dependent upon the reliability of the method and the accuracy of collecting samples and analyzing them.

Surprisingly close agreement has been noted thus far in analysis of duplicate samples from many fields. These duplicates always originate in widely separated stations. Many varieties and different ages of cane have been examined for the effect on inherent nitrogen variability. While H 109 gave the closest agreement, other varieties like 31-1389, POJ 2878, H 8965 and 27-8101 are not extremely variable in this respect. In H 109 cane growing uniformly in a field, it appears that the difference between duplicate determinations of nitrogen index values is usually found at minimum or not exceeding 0.20 per cent total nitrogen. For other varieties similarly checked, the difference may exceed 0.20 per cent but the variability usually falls within 0.40 per cent total nitrogen. Thus for the variety H 109 it may appear that where the difference between the averages of two duplicate sets of analyses determined at different intervals of growth does not exceed 0.20 per cent total nitrogen, the variation may be due to analytical error. However, where the difference exceeds 0.40 per cent, it may be accepted as reliably significant.

The variation in nitrogen index values of H 109 was studied by one of us in a plant crop. Eight plots of 3 lines each, at Makiki, were located in widely separated parts of a quarter-acre field divided into sixty plots. Leaf-punch samples were taken from each plot and analyzed separately. The data resulting from analyses made on leaf-punch specimens from the eight plots were averaged and the probable error of the mean (PEm) and coefficient of variation per sampling were determined. The first samples were taken at the age of six weeks and at each monthly and sometimes bi-weekly intervals. Eleven sets of samples were secured during a crop interval of 8 months. The average percentage content of each set ranged from 1.72 per cent to 2.43 per cent. The probable error of the mean for each set per sampling period fluctuated between 0.02 and 0.05 per cent total nitrogen. The coefficients of variation ranged from 2.3 per cent to 6.5 per cent, with the majority within 4 per cent. Similar results were obtained with POJ 2878 in the same field.

A preliminary presentation is offered of the results of the leaf-punch nitrogen study so far concluded in the effort to establish a physiological basis for the analysis in controlling nitrogen fertilization of sugar cane. The investigation embraces (a) *a study of the relationship between nitrogen content of the leaf disks and the growth of sugar cane in pots,* (b) *a study of field results, and* (c) *a presentation of a tentative procedure which may aid in the practical control of nitrogen fertilization.*

Pot Experiment on Cane Growth

It is generally accepted, we believe, that in many plants and especially sugar cane (as shown in many other experiments) the nitrogen content of the foliage fluctuates from a high level during the young stages of growth to a low value at maturity. In order that any method of leaf analysis may be applicable to the purpose of fertilization control, a relationship should exist between the nitrogen content determined at any time of growth and the stage of the plant development under study at that time. A pot experiment was conducted to ascertain if such a positive relationship, if any, existed and, if so, to what extent and to what degree the course of nitrogen variation fluctuated in the leaf system concurrently with growth.

Experimental Plan:

In this experiment pregerminated H 109 cane shoots were grown in Mitscherlich pots, using a Manoa acid soil from Field 5. Sufficient phosphate and potash (9.0 grams P_2O_5 from solution of superphosphate, and 3.0 grams K_2O from potash sulfate) were mixed with 4½ kilograms of air-dry soil at the time of potting to eliminate the deficiency of these nutrients in the experiment. Nitrogen, therefore, became the limiting factor under study. Nitrogen treatments provided for three comparative levels of fertility (deficiency, sufficiency, and excess) with additional check pots to which no nitrogen fertilizers had been added.

The experiment consisted of 24 pots. Two pots did not receive nitrogen. The remaining pots were divided into two series of 11 each. One series received nitrogen as sulfate of ammonia and the other as nitrate of soda.

The treatments furnished the following amounts of nitrogen: 0, 1, 1½, 2, and 3 grams of nitrogen to each pot of two stalks. Within each series the nitrogen was split into two applications, excepting the 1½-gram treatment. For the split applications, one-half of each treatment was applied two weeks after potting. Variable times of application entered into the addition of the remaining half. For one subseries, the remaining half was applied as soon as R.C.M. (rapid chemical methods) analysis showed the first application to be depleted from the soil. For another subseries, the remaining half was applied when the plants showed definite yellowing of foliage.

Summarizing: the experiment was divided into two series: (*a*) sulfate of ammonia treatment, and (*b*) nitrate of soda. For each series, nitrogen applications were made of 0, 1, 1½, 2, and 3 grams of nitrogen in the following manner:

2 pots no nitrogen treatment—same pots are common for each series
2 pots 1-gram nitrogen treatment (deficiency level)
  ½ gram at 2 weeks
  ½ gram when R.C.M. soil analysis showed depletion of first application
2 pots 1-gram nitrogen treatment
  ½ gram at 2 weeks
  ½ gram upon yellowing of foliage
2 pots 2-gram nitrogen treatment (sufficiency level)
  1 gram at 2 weeks
  1 gram when R.C.M. soil analysis showed depletion of first application
2 pots 2-gram nitrogen treatment
  1 gram at 2 weeks
  1 gram upon yellowing of foliage
2 pots 3-gram nitrogen treatment (excess level)
  1½ grams at 2 weeks
  1½ grams when R.C.M. soil analyses showed depletion of first application
1 pot 1½-gram nitrogen treatment, one application at 2 weeks.

Two plants only were allowed to grow in each pot. As soon as suckers emerged from the soil they were removed. Periodic sampling of the leaves of the two plants per pot were made at frequent intervals by the leaf-punch technic. At the younger stages only the first fully opened leaf was sampled. As the growth of the plants progressed with the development of a complete leaf system, sampling was conducted

in a manner comparable to the regular procedure previously described and confined to the prescribed grouping of leaves.

The disk specimens were analyzed by the regular rapid chemical method developed for this work. Due to the smaller quantity of material taken for analysis, the method was modified only to the extent of facilitating colorimetric reading and calculation of data. Results expressed as percentage of total nitrogen were reported on both the green- and dry-weight bases of the samples.

Commencing with six weeks after potting and at periodic intervals coincident with leaf punching, linear growth measurements were made of each stalk of cane, measuring from a fixed base level on the pot to the uppermost visible dewlap of the stalk.

Soil analyses were made only up to the depletion of the initial application for each treatment in order to control the addition of the second half as planned.

Results:

The data presented will cover only the nitrogen percentages of the leaf samples and the growth measurements. They represent averages for each treatment. Soil data obtained only for control will not be reported. Tables III, IV, VI, and VII give the nitrogen percentages of the leaf-punch samples on both the green- and dry-weight bases. The data on accumulative elongation of the stalk for each treatment are presented in Tables V and VIII.

Due to limited greenhouse facilities during the conduct of the experiment, the series of nitrate of soda pots was often subjected to shading which did not occur to any great extent in the sulfate of ammonia series. Shading favored greater elongation in the nitrate pots. While the data of the two series are not exactly alike, they are comparable and lead to similar and parallel conclusions. For purposes of simplification and clarity, the results of the sulfate of ammonia series only will be discussed later.

Reporting of Data:

Differences of opinion exist as to the manner of expressing the results of analysis of plant materials for inorganic constituents. There are those who favor reporting results on the fresh- or green-weight basis of the samples as being best indicative of metabolic processes. Others favor a dry-weight basis as being more nearly correct due to the elimination of dilution of a small quantity of nutrients by a large proportion of moisture which is associated with most plant materials. The general conclusion at present appears to be that the procedure should be followed which is best suited for individual purposes. From results of this investigation it appears that expression of nitrogen data on the dry-weight basis is best suited for our purpose.

TABLE III

PER CENT TOTAL NITROGEN IN LEAF DISKS (DRY BASIS) AT PROGRESSIVE INTERVALS

Sulfate of Ammonia Treatments

Applications: ½ of total quantity applied at 2 weeks
Remaining half applied (underlined):
(*a*) When R.C.M. soil analysis showed depletion
(*b*) Upon yellowing of foliage

Weeks	0 Check	1 gm. N (*a*)	1 gm. N (*b*)	2 gms. N (*a*)	2 gms. N (*b*)	3 gms. N (*a*)	1½ gms. N at 2 wks.
Start	1.97						
2.....	3.42	2.81	2.81	2.72	2.72	2.60	2.60
4.....	3.39	3.30	3.30	3.16	3.16	3.64	3.64
6.....	2.84	3.44	3.44	3.44	3.44	3.40	3.40
8.....	1.46	2.64	2.64	2.52	2.52	2.56	2.56
10.....	1.43	2.46	2.46	2.49	2.49	2.97	2.97
12.....	1.32	2.43	1.69	2.34	2.34	2.54	2.54
14.....	1.09	1.80	1.62	2.14	2.14	2.48	2.48
16.....	1.09	1.52	1.27	2.36	1.67	2.05	2.05
18.....	0.74	1.17	1.39	1.66	1.14	1.50	1.50
20.....	0.86	1.17	1.52	1.74	1.22	2.08	1.57
22.....	0.90	1.04	1.46	1.38	1.66	1.90	1.25
24.....	0.78	1.08	1.08	1.14	1.44	1.66	0.95
26.....	1.06	1.02	1.04	1.16	1.26	1.47	1.06
28.....	0.93	0.80	0.84	0.92	1.12	1.31	0.94
30.....	0.90	0.75	0.81	0.96	0.94	1.10	0.84
32.....	0.97	0.73	0.72	0.74	0.99	0.98	0.80
36.....	0.85	0.67	0.64	0.74	0.78	0.87	0.69

TABLE IV

PER CENT TOTAL NITROGEN IN LEAF DISKS (GREEN BASIS) AT PROGRESSIVE INTERVALS

Sulfate of Ammonia Treatments

Applications: ½ of total quantity applied at 2 weeks
Remaining half applied (underlined):
(*a*) When R.C.M. soil analysis showed depletion
(*b*) Upon yellowing of foliage

Weeks	0 Check	1 gm. N (*a*)	1 gm. N (*b*)	2 gms. N (*a*)	2 gms. N (*b*)	3 gms. N (*a*)	1½ gms. N at 2 wks.
Start	0.47						
2.....	1.20	1.03	1.03	0.97	0.97	0.83	0.83
4.....	1.39	1.24	1.24	1.23	1.23	1.50	1.50
6.....	0.80	1.01	1.01	1.16	1.16	1.07	1.07
8.....	0.53	0.99	0.99	0.92	0.92	0.93	0.93
10.....	0.47	0.79	0.79	0.80	0.80	0.92	0.92
12.....	0.47	0.76	0.50	0.70	0.70	0.79	0.79
14.....	0.40	0.56	0.52	0.66	0.66	0.79	0.79
16.....	0.40	0.52	0.45	0.80	0.55	0.68	0.68
18.....	0.30	0.42	0.50	0.62	0.36	0.50	0.50
20.....	0.28	0.37	0.48	0.55	0.38	0.66	0.55
22.....	0.31	0.34	0.48	0.44	0.57	0.64	0.42
24.....	0.30	0.38	0.36	0.40	0.53	0.54	0.32
26.....	0.37	0.35	0.34	0.37	0.40	0.46	0.36
28.....	0.34	0.29	0.29	0.32	0.35	0.46	0.34
30.....	0.32	0.26	0.29	0.33	0.31	0.38	0.31
32.....	0.35	0.27	0.28	0.28	0.35	0.36	0.30
36.....	0.31	0.25	0.25	0.28	0.29	0.31	0.26

TABLE V

ACCUMULATIVE STEM ELONGATION (IN CENTIMETERS) PER POT OF TWO STALKS AT PROGRESSIVE INTERVALS

Sulfate of Ammonia Treatments

Nitrogen applications: ½ of total quantity applied at 2 weeks
Remaining half applied (underlined):
(*a*) When R.C.M. soil analysis showed depletion
(*b*) Upon yellowing of foliage

Weeks	0 Check	1 gm. N (*a*)	1 gm. N (*b*)	2 gms. N (*a*)	2 gms. N (*b*)	3 gms. N (*a*)	1½ gms. N at 2 wks.
6.....	0.9	2.7	2.7	3.7	3.7	2.4	2.4
8.....	1.9	12.8	12.8	10.6	10.6	7.7	7.7
10.....	2.3	19.6	19.6	18.4	18.4	14.7	14.7
12.....	2.6	28.0	23.8	28.8	28.8	25.9	25.9
14.....	2.6	35.6	26.1	35.7	35.7	34.4	34.4
16.....	2.6	39.8	27.5	48.4	41.3	43.7	43.7
18.....	2.6	42.1	40.0	59.0	46.4	51.1	51.1
20.....	2.7	43.9	48.2	64.8	48.4	57.1	57.2
22.....	2.7	44.5	51.0	68.5	54.6	68.1	62.2
24.....	2.7	46.1	52.4	71.1	66.3	71.9	64.2
26.....	2.8	46.7	54.0	76.5	74.6	77.9	64.3
28.....	3.8	47.0	54.6	82.1	81.0	87.1	64.9
30.....	3.9	47.4	55.6	85.5	83.3	92.1	65.0
32.....	4.2	48.1	56.3	87.3	86.4	98.7	67.7
34.....	4.7	48.3	56.5	88.9	90.2	103.6	68.9
36.....	5.9	48.9	59.5	95.5	98.8	112.8	70.0
38.....	7.3	50.1	61.8	101.1	107.4	121.5	75.3
40.....	7.9	50.7	63.2	104.9	110.7	124.6	76.1
42.....	9.0	50.9	64.4	110.8	115.0	128.2	76.2
44.....	9.8	51.0	65.8	113.5	118.8	129.6	76.2
46.....	11.2	51.4	68.7	115.5	121.5	133.1	77.7
48.....	11.5	52.4	70.4	117.0	125.3	137.3	78.2
50.....	12.1	53.0	71.4	117.4	127.5	138.9	79.8
52.....	12.9	53.2	71.7	117.7	129.2	140.3	80.5

TABLE VI

PER CENT TOTAL NITROGEN IN LEAF DISKS (DRY BASIS) AT PROGRESSIVE INTERVALS

Nitrate of Soda Treatments

Applications: ½ of total quantity applied at 2 weeks
Remaining half applied (underlined):
(*a*) When R.C.M. soil analysis showed depletion
(*b*) Upon yellowing of foliage

Weeks	0 Check	1 gm. N (*a*)	1 gm. N (*b*)	2 gms. N (*a*)	2 gms. N (*b*)	3 gms. N (*a*)	1½ gms. N at 2 wks.
Start	1.97						
2.....	3.42	2.66	2.66	2.63	2.63	2.51	2.51
4.....	3.39	2.82	2.82	3.33	3.33	3.29	3.29
6.....	2.84	3.34	3.34	3.37	3.37	3.20	3.20
8.....	1.46	2.56	2.56	2.47	2.47	2.54	2.54
10.....	1.43	2.68	2.68	2.86	2.86	3.48	3.48
12.....	1.32	2.30	2.02	2.35	2.35	2.82	2.82
14.....	1.09	2.49	2.11	2.36	2.36	2.67	2.67
16.....	1.09	1.96	1.48	2.31	2.08	2.35	2.35
18.....	0.74	1.47	1.66	1.92	1.50	1.90	1.90
20.....	0.86	1.38	1.69	1.84	1.48	2.02	1.33
22.....	0.90	1.06	1.36	1.60	1.76	1.86	1.10
24.....	0.78	0.88	1.03	1.46	1.45	1.68	1.00
26.....	1.06	0.81	0.98	1.27	1.37	1.62	0.98
28.....	0.93	0.84	0.86	0.99	1.08	1.10	0.82
30.....	0.90	0.80	0.84	1.05	1.21	1.24	1.04
32.....	0.97	0.73	0.76	0.98	0.85	0.97	0.91
36.....	0.85	0.66	0.68	0.75	0.73	0.83	0.75

TABLE VII

PER CENT TOTAL NITROGEN IN LEAF DISKS (GREEN BASIS) AT PROGRESSIVE INTERVALS

Nitrate of Soda Treatments

Applications: ½ of total quantity applied at 2 weeks
Remaining half applied (underlined):
(*a*) When R.C.M. soil analysis showed depletion
(*b*) Upon yellowing of foliage

Weeks	0 Check	1 gm. N (*a*)	1 gm. N (*b*)	2 gms. N (*a*)	2 gms. N (*b*)	3 gms. N (*a*)	1½ gms. N at 2 wks.
Start	0.47						
2.....	1.20	0.97	0.97	0.94	0.94	0.79	0.79
4.....	1.39	1.16	1.16	1.38	1.38	1.38	1.38
6.....	0.80	0.99	0.99	0.95	0.95	0.93	0.93
8.....	0.53	0.90	0.90	0.87	0.87	0.89	0.89
10.....	0.47	0.82	0.82	0.85	0.85	1.01	1.01
12.....	0.47	0.73	0.62	0.70	0.70	0.85	0.85
14.....	0.40	0.75	0.66	0.71	0.71	0.81	0.81
16.....	0.40	0.68	0.49	0.75	0.65	0.76	0.76
18.....	0.30	0.52	0.56	0.62	0.47	0.61	0.61
20.....	0.28	0.42	0.53	0.55	0.42	0.60	0.39
22.....	0.31	0.34	0.44	0.52	0.56	0.60	0.36
24.....	0.30	0.30	0.34	0.48	0.48	0.58	0.35
26.....	0.37	0.28	0.33	0.42	0.46	0.52	0.32
28.....	0.34	0.33	0.28	0.39	0.42	0.41	0.32
30.....	0.32	0.28	0.28	0.37	0.40	0.42	0.38
32.....	0.35	0.27	0.26	0.32	0.30	0.34	0.34
36.....	0.31	0.23	0.26	0.28	0.27	0.32	0.29

TABLE VIII

ACCUMULATIVE STEM ELONGATION (IN CENTIMETERS) PER POT OF TWO STALKS AT PROGRESSIVE INTERVALS

Nitrate of Soda Treatments

Nitrogen applications: ½ of total quantity applied at 2 weeks
Remaining half applied (underlined):
(*a*) When R.C.M. soil analysis showed depletion
(*b*) Upon yellowing of foliage

Weeks	0 Check	1 gm. N (*a*)	1 gm. N (*b*)	2 gms. N (*a*)	2 gms. N (*b*)	3 gms. N (*a*)	1½ gms. N at 2 wks.
6.....	0.9	3.8	3.8	3.4	3.4	2.9	2.9
8.....	1.9	11.7	11.7	10.7	10.7	7.8	7.8
10.....	2.3	17.6	17.6	17.6	17.6	13.2	13.2
12.....	2.6	23.9	24.6	28.7	28.7	27.1	27.1
14.....	2.6	30.1	26.4	36.2	36.2	34.6	34.6
16.....	2.6	38.9	27.4	47.0	45.3	47.5	47.5
18.....	2.6	45.7	43.6	61.0	53.1	60.2	60.2
20.....	2.7	50.7	52.9	73.0	58.9	65.3	63.0
22.....	2.7	52.5	56.6	82.2	65.7	69.0	66.7
24.....	2.7	53.1	57.6	90.6	79.8	78.0	67.6
26.....	2.8	53.8	59.2	98.6	91.0	88.5	72.3
28.....	3.8	56.0	61.1	104.3	101.7	98.9	76.9
30.....	3.9	56.8	62.3	107.9	110.2	106.2	80.7
32.....	4.2	57.2	64.1	109.8	120.6	112.4	84.4
34.....	4.7	57.3	65.5	110.5	126.8	116.3	86.7
36.....	5.9	59.7	72.4	113.5	139.9	124.7	92.1
38.....	7.3	61.6	75.9	116.5	152.7	133.1	98.9
40.....	7.9	62.2	77.3	117.5	158.1	137.7	104.2
42.....	9.0	62.2	77.9	117.5	161.7	139.9	107.1
44.....	9.8	62.2	80.7	117.5	162.3	141.6	107.7
46.....	11.2	63.3	83.5	118.8	163.3	146.7	110.1
48.....	11.5	65.4	87.6	120.0	165.7	151.8	111.4
50.....	12.1	66.2	90.0	120.2	168.0	154.0	111.9
52.....	12.9	67.4	91.5	120.6	168.5	155.7	112.3

An inspection of Tables III and IV will reveal that similar trends may be noted for nitrogen values determined at progressive intervals and expressed on both bases. However, values on the dry-weight basis are much higher than those calculated on green weights. It appears, therefore, that greater differences may be detected with the dry-weight data. A tabulation of the 2-gram nitrogen from sulfate of ammonia treatment is given to illustrate this point.

PER CENT TOTAL NITROGEN IN LEAF SAMPLES

Green-weight basis	Dry-weight basis
.97	2.72
.92	2.52
.80	2.49
.80	2.36
.70	2.34
.66	2.14
.62	1.66
.55	1.74
.44	1.38
.40	1.14
.37	1.16
.33	0.96
.32	0.92
.28	0.74

From the above data it is apparent that the differences between the highest and the lowest values are 0.69 per cent total nitrogen for the green-weight basis and 1.98 per cent for the dry basis. A wider range of fluctuation is possible for the dry-weight values. Its effect on showing differences is apparent on comparing a few data. For instance, if 0.66 per cent and 0.62 per cent green-weight basis are compared, the difference between the two values is 0.04 per cent, which may be too small to be significant for practical and routine operation. However, with their corresponding dry-weight values, the difference between 2.14 per cent and 1.66 per cent becomes 0.48 per cent total nitrogen and may be accepted as reliable. For a narrow fluctuation between 0.40 per cent and 0.55 per cent on the green-weight basis, their dry-weight values become 1.14 per cent and 1.74 per cent.

Any changes in the moisture content of the leaf samples as influenced by the time of day sampled, age of cane, recent rainfall or irrigation and seasonal differences may have an effect on the variation of the nitrogen content on the green-weight basis of the samples collected. It is thus difficult to determine whether fluctuations are due to normal changes of growth or whether they are due primarily to differences in moisture content of the samples. However, when the results are expressed on the dry-weight basis, at least one source of fluctuation is eliminated. The effect of rainfall on the nitrogen content has been definitely shown to change the fresh-weight results without affecting the dry-weight values. In this regard a study of the effect of rainfall by Fagan has been reported by Nishimura and Hance (13).

In addition to the absorbed moisture, the extraneous moisture adhering to the leaf from dew and showers make sampling difficult when results are to be expressed on the green-weight basis. Thus, in addition to physiological differences noted, the

difficulties encountered in an actual field procedure makes reporting on a green-weight basis undesirable and less practical. For these reasons the analytical data determined on the organized leaf-punch study, using a standardized sampling and analytical procedure, are reported on the moisture-free basis. In subsequent discussions, the data under consideration will refer to cane leaf nitrogen index values on the moisture-free basis. In Figs. 1, 2 and 3, nitrogen curves on the green-weight basis are included for inspection only.

Discussion of Results:

The Limits of Nitrogen Percentage Values Determined by Leaf Punch During Cane Growth: Graphs of nitrogen indices are obtained by plotting the percentages of total leaf nitrogen on the ordinate (Y-axis) and the time or age interval on the abscissa (X-axis). In Figs. 1, 2 and 3 are presented the growth and nitrogen data for the check pots and those for the sulfate of ammonia treatment. The graphs of the dry-weight nitrogen data are typical of those obtained from the field for cane leaf analysis carried out by this method of study.

Examining the graph for the check pots it may be noted that from an initial figure of 1.97 per cent total nitrogen determined at the time of potting, the value increased to 3.42 per cent two weeks after potting. This value represents the highest obtained for these check pots. The curve dropped progressively with growth from this highest point to a low of about 1 per cent.

In the fertilized pots the nitrogen value two weeks after potting rose from 1.97 per cent to about 2.75 per cent, then to a high of 3.4 per cent two weeks after fertilization. From then on the curve dropped progressively with growth to a low of approximately 1 per cent and fluctuated between this value and 0.8 per cent.

In general, it appears that the highest values are obtained during the very young stage of growth of the cane plant. The curve then drops progressively. However, the slope of the curve depends to a certain extent upon the *time of application* and the quantity of nitrogen applied. From results of this experiment and subsequent pot and field studies, the maximum reached for percentage total nitrogen, irrespective of variety, is about 3 per cent. However, this value is usually reached prior to the age of three months and depends to a large extent upon the fertility of the soil with respect to all plant foods and the amount of nitrogen fertilization added. For field crops the highest value is closer to 2.6 per cent. The lowest value to which the nitrogen index is reduced in a normal crop may be placed at 1 per cent. Thus, the maximum range of fluctuation to be found in leaf-punch analysis is between 3 per cent and 1 per cent, regardless of variety or fertilization. That is, irrespective of whether the crop received no nitrogen or whether it was fertilized with 400 pounds of this nutrient, the leaf nitrogen values will fluctuate within these limits. The time required for the value to drop from the maximum to the minimum is, to a large degree, influenced by the quantity of nitrogen applied and absorbed by the plant. This is illustrated in Fig. 4.

In Fig. 4 nitrogen percentage curves are presented as representing the check and fertilized pots. These graphs show clearly that the time required for each curve to reach a minimum is dependent upon the amount of nitrogen received by the plants.

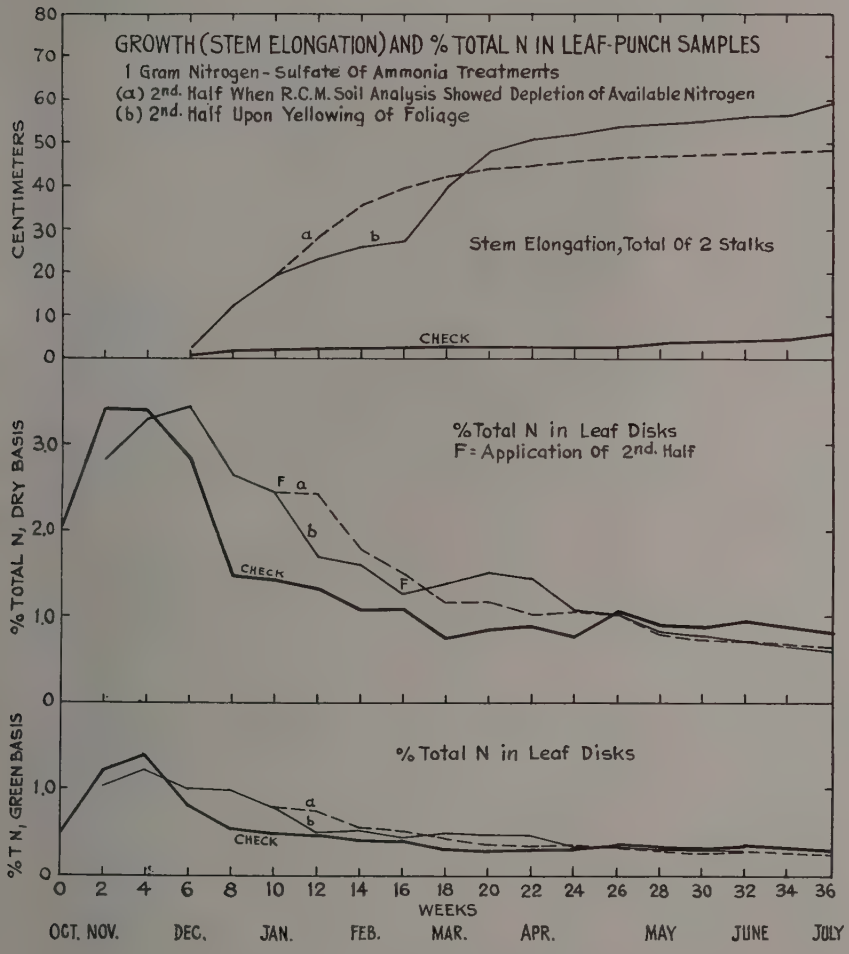

Fig. 1

For the check or no-nitrogen pots, the curve dropped to the minimum level within 14 weeks after potting. For the others it ranged from 20 to 32 weeks, depending upon the fertilization.

Effect of Fertilization Upon Trend of Curve: While the nitrogen indices may fluctuate within the limits stated, it is desirable to examine the data to determine to what extent these values may reflect differential applications of nitrogen. From a study of the fertilized pots in Fig. 4 it appeared that during the start of the crop the nitrogen indices were alike for all treatments. However, as growth progressed different values were obtained for the treatments at a given instant. This is to be expected if the interval required for the lowering to a minimum value is dependent upon the amount of nitrogen applied and growth of the crop. (It will be noted that the fluctuations occurred within or nearly within the previously stated range of values.)

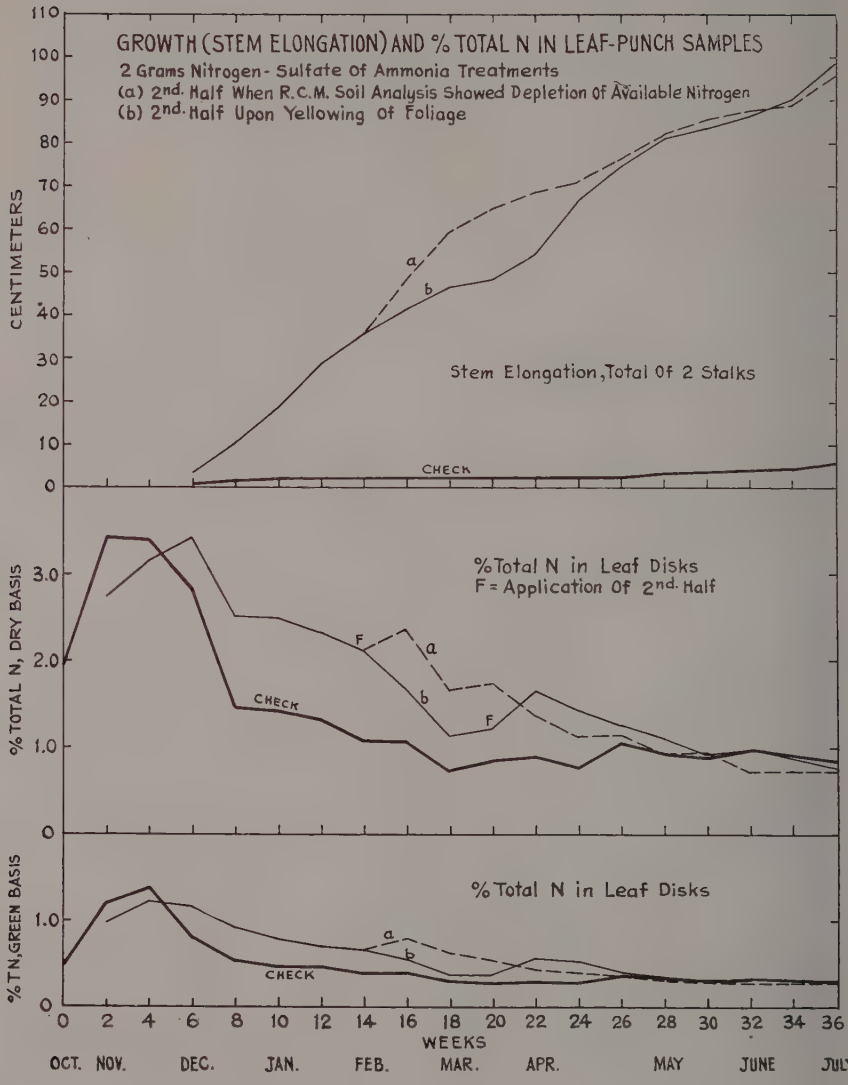

Fig. 2

The above discussion is based on data obtained in a pot experiment where only the original or primary stalk was developed. However, under field conditions where all orders of stalks are allowed to develop in one stool of cane, such differences in leaf nitrogen content may not become as readily apparent. Under field conditions, as the amount of nitrogen is increased for a given area, increase in tillering is usually obtained in addition to a development of larger leaf area per stalk. These increases in plant development may operate to equalize the excess which can accumulate if the primary stalk only is allowed to grow.

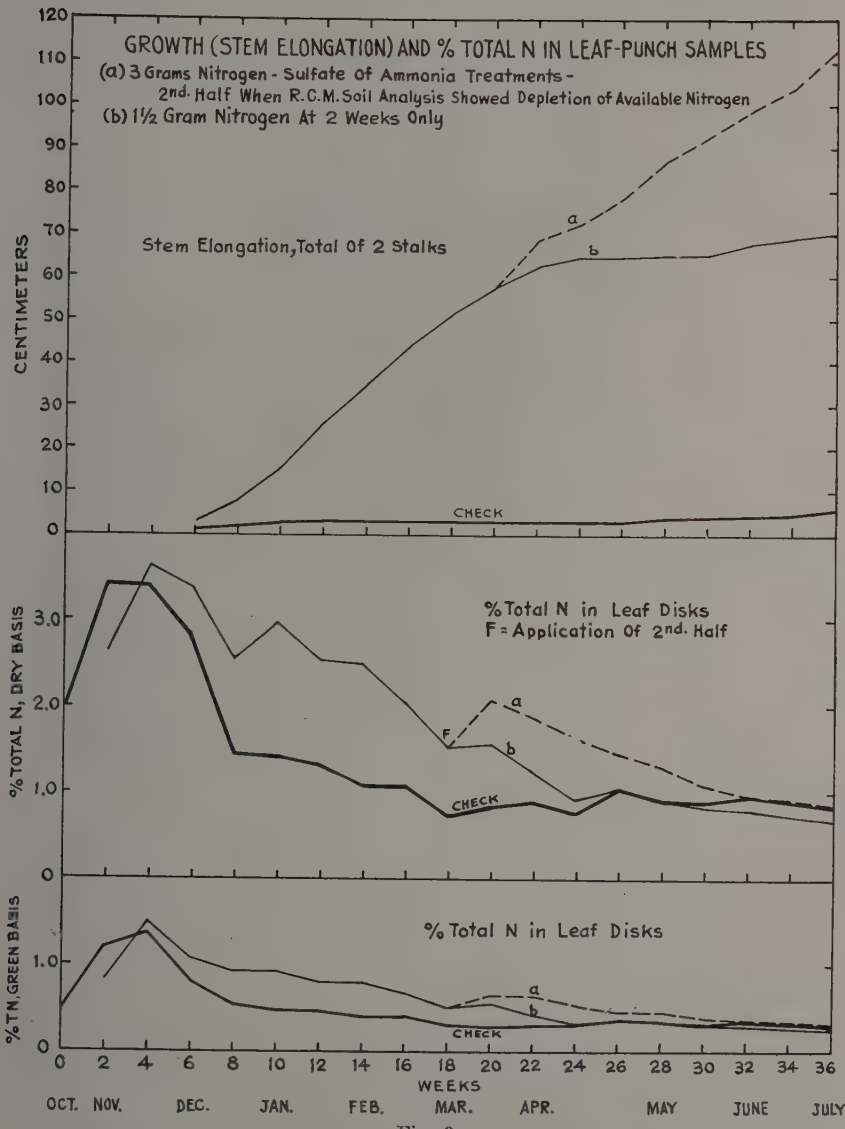

Fig. 3

In general field practice, the nitrogen requirement for a crop is usually split into several applications and applied at different times. It is desirable to know in what manner nitrogen applications may affect the index level shortly following fertilization.

The pot experiment under study provided for the conditions of a "time-of-application" and an "amounts-of-nitrogen" test. The solution of this question, therefore, may become apparent from an examination of Figs. 1, 2, 3 and 4. The results appear to indicate that fertilization may either (*a*) raise the nitrogen level

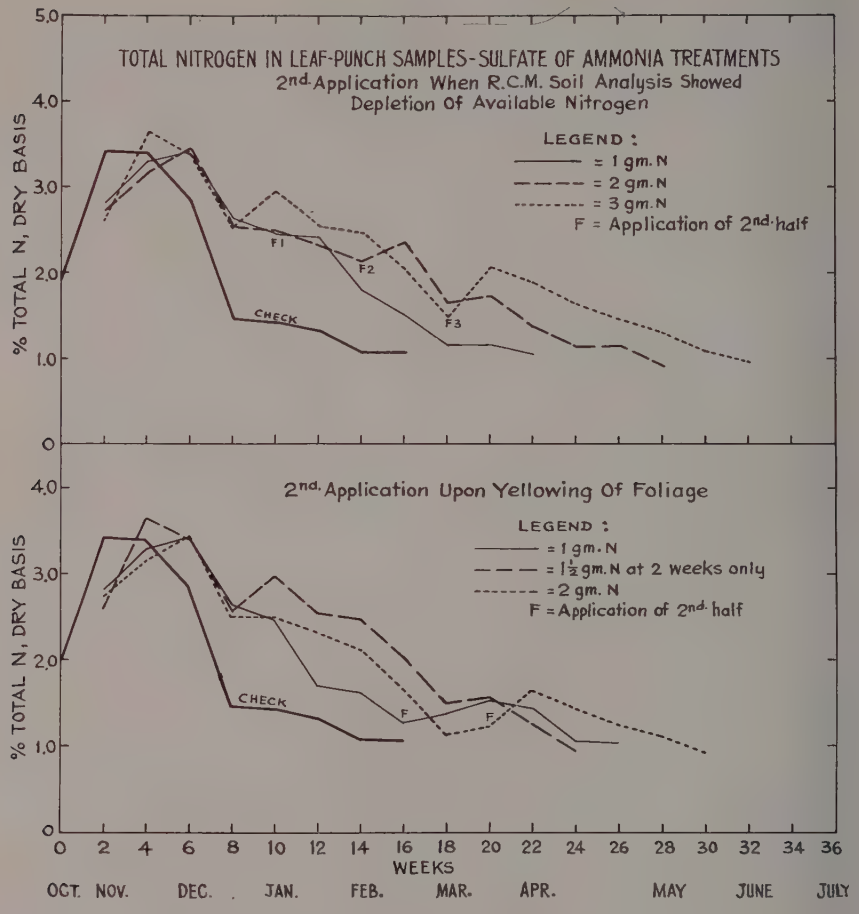

Fig. 4

above the one preceding fertilization, (*b*) continue the present level, or (*c*) show no effect, that is, the level may continue to drop smoothly without interruption. Whichever manner the curve may develop is probably dependent upon the interval following last application, the amount of nitrogen previously absorbed, the amount of the current application, the age of the crop and the time of application with respect to season.

Relationship Between Nitrogen Index and Growth: The nitrogen curve itself was treated in the foregoing paragraphs. Its trend and development as influenced by fertilization were touched upon. The present discussion concerns the relationship between the nitrogen indices determined and the growth of sugar cane in pot culture.

It was shown that in the course of cane growth the nitrogen index of the plant fluctuated from 3 per cent as the maximum to 1 per cent as the minimum, and that the time required to reach the minimum was dependent upon the amount of nitrogen applied and absorbed, assuming that nitrogen alone was the limiting factor. The

problem, then, is to determine the significance of these values with respect to growth. Growth in this study refers to linear development.

Reasons for Measuring Elongation: It is admitted that elongation of the stem is only one phase in any growth measurement and that the gain in dry matter may proceed even when the linear development has slackened or ceased. However, until a method is devised which can integrate the various growth measurements, the estimation of elongation alone will have to suffice. Under ideal conditions where nitrogen is the limiting factor, it is generally accepted that a high supply of nitrogen in the plant is associated with increased or prolonged vegetative growth. Where such vegetative growth in sugar cane is allowed to proceed at an undiminished rate until close to harvest, it is believed that the resulting crop usually will be poor in quality although high in cane yield. Thus, for nitrogen fertilization, the optimum may be reached where vegetative growth can be balanced to permit greater opportunity for carbohydrate accumulation. Therefore, the measurement to be taken is one which will indicate vegetative growth or conditions for potential vegetative development. Since elongation is a function of vegetative growth, its measurement may then be taken for the purpose of this study.

Correlations: Growth measurements of the cane grown under the various treatments of this experiment are presented in Figs. 1, 2 and 3. The data cover the growth in the pots from the sixth to the thirty-sixth week. Correlation between growth and the nitrogen index is apparent from a study of these graphs.

It will be recalled that in this experiment the nitrogen for each treatment (amounts of nitrogen), except the 1½-gram pots, was divided into two equal parts. The initial half was applied to all pots alike at two weeks after potting and the remaining half was applied either (*a*) when the first application was depleted, or (*b*) upon yellowing of foliage.

Examining Fig. 1 of the deficiency level, nitrogen treatment, and in particular the yellowing of foliage sub-treatment, it will be noted that the growth was affected by the amount of nitrogen applied and the time of application. The rate of elongation in the delayed application sub-series was higher during the sixth to the tenth week than between the tenth and sixteenth week. The total nitrogen content found in the leaf samples was between 3.4 per cent and 2.4 per cent in the first period and during the interval following was between 2.4 per cent and 1.3 per cent. When the final half of fertilizer was applied in the sixteenth week, the level was again raised to 1.5 per cent and growth increased. When the level dropped to about 1 per cent, the growth was practically negligible. In the complementary sub-series, when the second application was not delayed, growth occurred at a high rate between the sixth to the sixteenth week when the nitrogen indices were between 3.4 per cent to 1.5 per cent. When the level reached 1.3 per cent the rate of growth rapidly diminished, and upon reaching the 1 per cent level, growth was practically negligible.

As the nitrogen supply approached the sufficiency level, for instance in the 1½-gram, single-application treatment, the growth curve paralleled the deficiency pots of 1-gram fertilization and continued to be correlated with the nitrogen percentage as in the lower treatment. This was shown in Fig. 3. However, as the nitrogen supply was increased with a higher level of fertility, the growth apparently did not correlate so closely with the nitrogen content of the leaf samples. Further examina-

tion at this stage will reveal interesting points on the relationship between nitrogen content of leaf specimens and growth of cane in pots.

It will be observed in the delayed-application sub-series of the 2-gram treatment, Fig. 2, that the growth occurring in the first application appeared to be still correlated with the nitrogen content during this period. However, after the second application, completing the sufficiency-level fertilization, growth did not follow the nitrogen curve as closely. This is to be expected since in the initial application the amount equalled only one gram of nitrogen, placing the supply still in the deficiency level so that the low level in the leaf nitrogen was reached early. In the other sub-series, when the last application followed the initial half immediately after soil depletion, growth was maintained at the initial high rate and did not slacken even when the 1.3 per cent level was reached for the leaf analysis. A closer study of the data will explain this apparent discrepancy between growth and leaf nitrogen content. Examining the upper portion of Fig. 4, it will be seen that the nitrogen content for the 2- and 3-gram treatments did not go below the 1.5 per cent level until the twenty-first and twenty-sixth week after potting and that upon passing this level the period of good growing weather was reached, that is, the summer months were approached. It therefore appears that good weather may act as a compensating factor for a low nitrogen level in the leaf area. In addition, translocation of nitrogen from other parts of the stalk may be sufficient to supply the needs for growth. Additional growth data for the entire period of the experiment are supplied in Figs. 5 and 6.

Summarizing: There appears to be a relationship between growth and the sufficiency of nitrogen and this sufficiency is indicated by the nitrogen content of the leaf sample. The critical low point below which growth stops is also affected by weather in addition to the sufficiency of the nitrogen supply.

From a study of the data at hand, it may be concluded tentatively that the nitrogen levels critically related to growth are:

2 per cent, above which there appears to be a luxury consumption.

1 per cent, minimum, desirable upon maturity.

Between 2 per cent and 1 per cent, growth proceeds normally, if other factors are not limiting. Above 1.5 per cent, nitrogen does not appear to be a limiting factor. Below 1.3 per cent growth diminishes or stops if weather is adverse. Growth may continue even at 1.3 per cent if weather is satisfactory. However, its rate may be affected.

If weather is optimum, the limiting level may be at 1 per cent, below which growth as elongation may be retarded. With good weather, translocation from other parts of the plant may furnish sufficient nitrogen for its growth, even if its level in the leaf area is at a minimum.

Results of Field Survey

Data and discussion are presented in the foregoing pages relative to leaf studies made with cane grown in pots. The question was raised as to whether data obtained from analysis of cane grown in the field under plantation practice are comparable to results similarly obtained from potted cane. In the early period of this investigation a survey was made in a number of plantation fields under the direction of Agee. Several plantations cooperated in making this survey. Samples were collected from random fields with the standardized leaf-punch procedure and analyzed

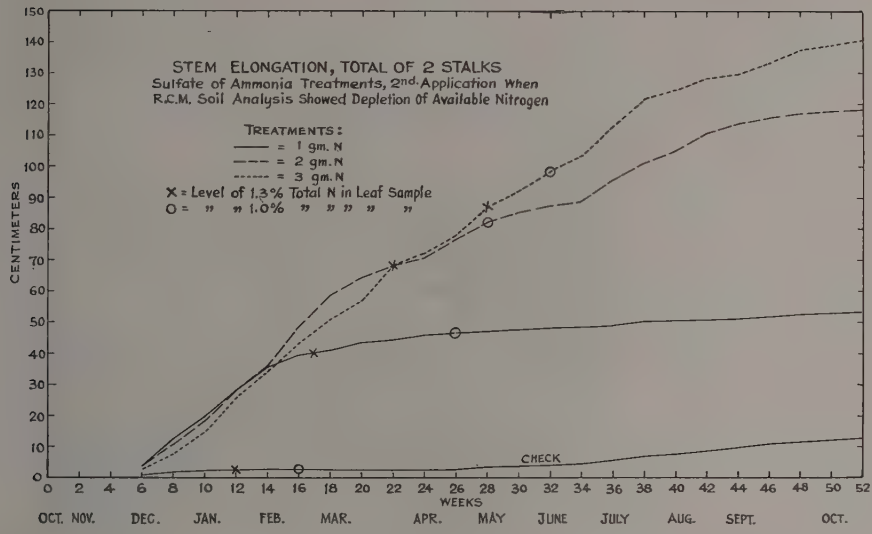

Fig. 5

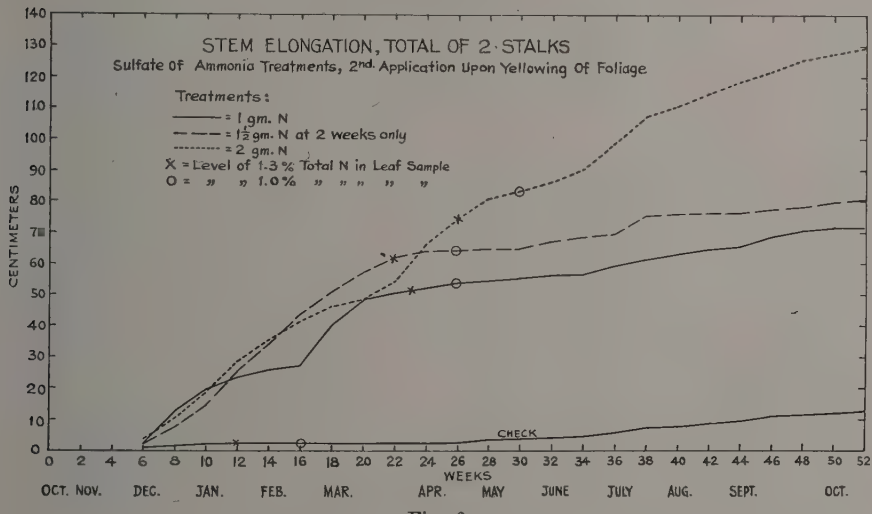

Fig. 6

by the regular rapid chemical method as previously explained. In the first step of this survey, collections were made from cane of different ages at one sampling period. Later the collection was extended so that certain fields were regularly sampled at progressive intervals. The objects of the survey were to determine the limits or range of nitrogen indices to be found in cane grown under regular systems of cultivation in established fields, to study the trend or the influence of age on the nitrogen content of the leaf zones believed sensitive and to learn facts regarding the variation in the nitrogen indices under the different conditions existing on various plantations. The results of this preliminary survey indicated that the range of values found in the field canes was similar to the one exhibited by the potted plants. The limits of indices remained between 2.7 per cent and 1.05 per cent. Young canes

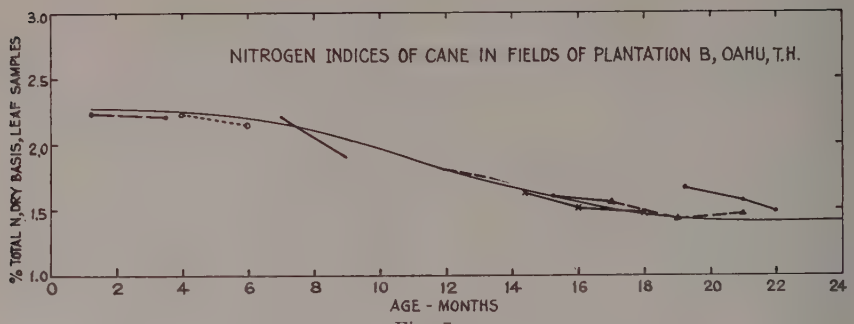

Fig. 7

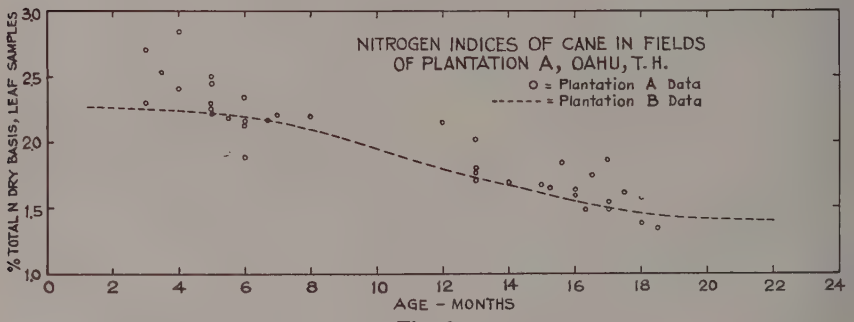

Fig. 8

up to about seven months of age were usually found to carry about 2.3 per cent nitrogen and those sampled at harvest, approximately 1.2 per cent for cane grown for about twenty-four months. Intermediate values were found for cane between the ages of 6 to 24 months. Part of the data from three plantations—two from Oahu and one from Maui—are presented in Table IX. It will be noted from these figures that the range of leaf nitrogen values were alike for a number of varieties and that there was a decrease in percentage content of the leaf zone progressively dropping with age of the cane.

As previously stated, a number of fields were sampled at regular intervals. In Fig. 7 are presented the data of Plantation "A," for eight fields, together with a smooth curve drawn by inspection, connecting these points. The rather uniform relationship existing between decrease of the nitrogen index with age of the cane grown on this plantation is illustrated by the curve. The variety under study was H 109. Fertilizer applied consisted of about 250 pounds nitrogen and applications were completed during the first six months of growth.

The data from Plantation "B," on this Island (Oahu), for H 109 cane are plotted in Fig. 8. The practice of the plantation for the crops under examination has been to apply approximately 250 pounds of nitrogen in two seasons, about two-thirds during the first season and the balance during the second season of growth. The smooth curve obtained for Plantation "A" is superimposed upon Fig. 8 so that a comparison may be made of the nitrogen indices obtained for cane grown in two different localities, reflecting probable differences in weather, fertilizer practices and soil and growth conditions. It will be noted that the points plotted for Plantation "B" in Fig. 8 are generally above the smooth curve representing Plantation "A" during the period under study.

TABLE IX

ANALYSIS OF LEAF-PUNCH SAMPLES TAKEN IN SURVEY COLLECTIONS OF PLANTATION FIELDS

Plantation "A"—Oahu

Field	Variety	Age at sampling	N-index % total N
R3	H 109	1 mo.	2.33
G3	31–1389	4½ mo.	2.14
R10A	31–2510	5½ mo.	2.18
R10A	H 109	9 mo.	2.20
KL18	H 8965	9 mo.	2.32
G5A	H 109	12 mo.	1.99
R5B	H 109	14 mo.	1.82
KL19A	H 109	21½ mo.	1.46
R8A	H 109	23 mo.	1.32
H18	H 109	24 mo.	1.20

Plantation "B"—Oahu

Field	Variety	Age at sampling	Interval since last N appl'n	lb N applied	Total lb N applied	N-index % total N
13A	H 109	1¼ mo.	2 days	57	57	2.24
1A	H 109	4 mo.	2 mo.	151	206	2.22
20A	H 109	7 mo.	2 mo.	129	251	2.20
2A–3D	H 109	12 mo.	7 mo.	91	254	1.80
6	H 109	14⅓ mo.	11 mo.	158	206	1.60
10C	H 109	17⅓ mo.	12 mo.	106	250	1.56
21B	H 109	19 mo.	13 mo.	88	248	1.66
23B	H 109	22 mo.	17 mo.	101	254	1.42
23B—Edge	H 109	22 mo.	17 mo.	101	254	1.05
15A	H 109	22 mo.	15 mo.	77	238	1.28

Plantation "C"—Maui

39	POJ 2878	4 mo.	3 mo.		53	1.88
47 Mauka	POJ 36	4 mo.			0	1.64
47 Makai	POJ 36	4 mo.			0	1.84
48	31–1389	9 mo.	3 mo.		123	2.07
17	POJ 2878	10 mo.	4 mo.		98	1.85
43	POJ 2878	12 mo.	10 mo.		112	1.72
30A	31–1389	12 mo.	3 mo.		87	1.99
2	31–1389	13 mo.	5 mo.		109	1.45
21	Y.C.	18 mo.	9 mo.		158	1.40

The effect of climate and environment on the nitrogen content of leaf samples of cane grown in different localities is further illustrated in Fig. 9. Here a study is made of the field and pot data. The variety under examination is H 109 and the fertilization of nitrogen per acre basis is nearly alike for either field or pots. The Makiki field data originated from an experimental plot of cane grown at the Makiki station for cane composition studies by Cornelison and Ayres. The curves of Plantations "A" and "B" reflect samplings made during the spring of 1938, the pot data during the winter of 1937 and spring of 1938, and the Makiki field data from the summer of 1936 to the winter of 1937. The results, therefore, appear to indicate

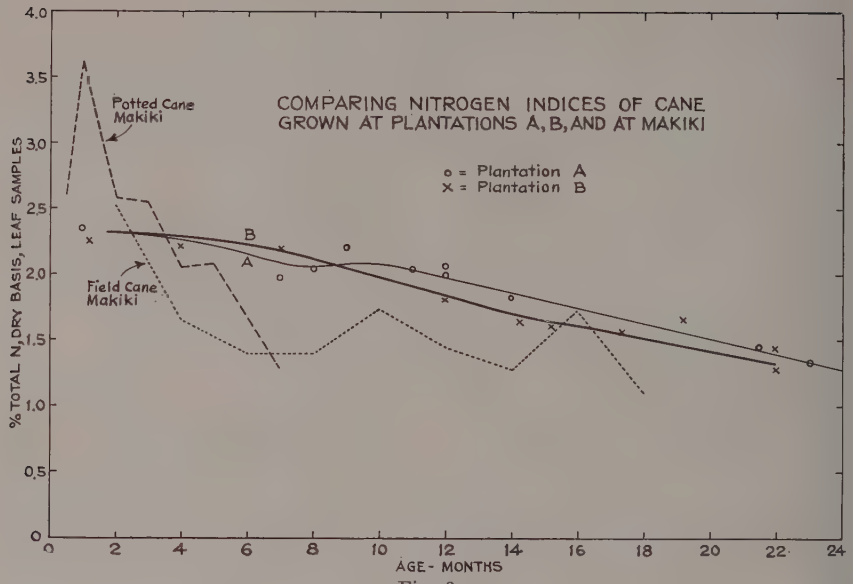

Fig. 9

that for a given variety of cane the curve of nitrogen percentages of the leaf samples collected at progressive intervals during the life of the crop may be affected by climatical and environmental factors (including soil and field practices). These factors affect growth and hence nitrogen absorption and utilization. These are reflected in the nitrogen indices determined.

Relation Between Percentage Nitrogen Content of Leaf Samples and Growth of Sugar Cane Under Field Conditions:

The similarity between the nitrogen content of leaves of potted cane and that of cane grown under field conditions as to nitrogen limits and the development of the nitrogen curve having been considered, the next matter of note refers to the relationship of nitrogen content of leaves and growth of cane in the field. Between the summers of 1936 and 1938, an experiment was conducted by Cornelison and Ayres (7) at the Makiki station in connection with the general research on basic studies of the sugar cane plant. During the period of the experiment, growth measurements of cane under various nitrogen treatments were taken by Cornelison. Leaf-punch analytical data were obtained by Mr. Davis for a study of the nitrogen economy of the sugar cane plant. In the present investigation, these data are re-examined and studied for the growth and leaf-punch nitrogen content relationship.

The elongation of primary stalks of the zero-nitrogen, the 100-pound, 250-pound and 400-pound nitrogen treatments, applied at the age of 1½ months, are shown in Fig. 10. The nitrogen percentage data of the corresponding treatments are also included in this chart. Growth measurements were taken from the fourth to the twenty-fourth month of growth while the nitrogen data covered only the period between the second and eighteenth months.

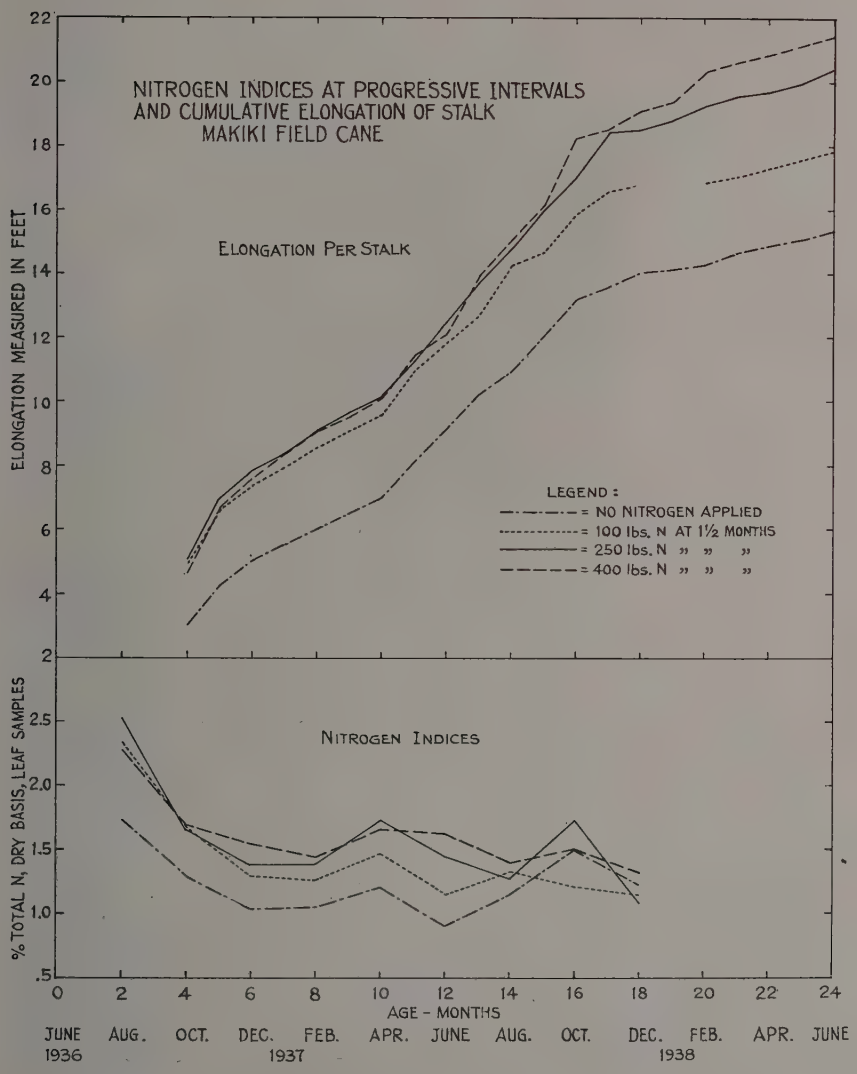

Fig. 10

Referring to the nitrogen curves of Fig. 10, a correlation appears to exist between the nitrogen levels and the fertilization made. In the zero-nitrogen plots, the level dropped from a high of 1.7 per cent to a low of 1.0 per cent within the interval of four months (age two to six months). In the treated plots, the levels were nearly alike for all treatments from the second to the fourth month of growth. From the sixth to the twelfth month a correlation appears to exist for the different amounts applied. During the first year's growth, the percentage nitrogen level of the leaf samples was lowest for the zero plots, while the 100-pound treatment was higher and did not drop to the level of the zero-nitrogen treatment at any time during this

period. It ranged from 2.3 per cent to 1.2 per cent. The next higher level was shown by the 250-pound treated plots. The highest level was reached by the 400-pound plots. However, the levels for both the 250- and 400-pound treated plots were nearly alike.

Turning now to the elongation curves, it will be seen that the total elongation appeared to be correlated with the fertilization. In the zero-nitrogen plots, growth was lowest, the next higher was the 100-pound treatment followed, still higher, by the 250- and 400-pound treatments, these latter showing very much the same elongation. Considering the elongation from the standpoint of nitrogen levels at any moment, it appears that even in the no-nitrogen plots elongation did not cease even when the level of 1.0 per cent was reached at the age of six months. As discussed in the pot studies, growth does not always stop when this low level is reached if other favorable factors for growth, especially weather, are optimum. It appears from the graph that the low level did not remain fixed at 1 per cent, but fluctuated occasionally above this value. It was shown in the other studies of this experiment by Ayres that the total nitrogen content of the entire aerial portion of the plant continued to increase even after the twelfth month, indicating, perhaps, that a small amount of soil nitrogen was continually becoming available and then absorbed. However, in spite of the continued growth, it appeared definitely from the study that with a low percentage nitrogen level, growth did not equal the fertilized pots at the start nor did it catch up with the others. In the 100-pound treatment, the low level fluctuated in the vicinity of 1.3 per cent which, as previously stated, was just about the lowest level to which the nitrogen value may drop without impairing growth. For the higher applications, the low level fluctuated closely around 1.5 per cent and the growth for these treatments was highest.

From results of this study of field data, the conclusion may be drawn that nitrogen levels in relation to stem elongation are effective for cane growing under field conditions as well as when cultivated under potted environment. It appears that if the nitrogen index level is at 1.5 per cent, H 109 may continue to elongate at a high rate if other factors are not limiting.

Having determined the development and trend of the nitrogen percentage curve of the leaf system of a growing cane crop and established the relationship between nitrogen levels in the leaf specimens and growth (elongation) of sugar cane, the matter of practical applications will be considered.

Developing Tentative Procedures for Nitrogen Control

A Review of Other Experiments:

Considerable attention has been devoted by many investigators in recent years to the development of methods of plant analysis which may lead to a determination of the mineral requirements of plants. Either the entire plant or parts thereof have been analyzed in seeking a means of learning its nutrient requirement. Leaf analysis as a proposed measure has the support of results obtained in many such studies. Thomas (14, 15) has described a system of leaf analysis based on the results of his own experiments on potatoes and apples considered with those of other continental investigators. This system of determining plant nutrient requirement is

known as "foliar diagnosis" and is defined by Thomas as a measure of the chemical condition or state of leaf with respect to the dominant nutritive elements at the instant of sampling. The sample is taken from a pre-determined and suitable position on the plant stalk. The foliar diagnosis for any given interval is defined as the sequence of chemical composition as determined at different periods during the growth period. This method departs from the usual in obtaining an analytical expression of plant performance in that the chemical composition of the leaf at different times is measured rather than determining the nutrient status of the soil or considering the nutrients added.

As previously stated, Lundegärdh (11) has proposed the analysis of the leaf in conjunction with soil analysis to determine the need of the plant *and* the fertility of the soil. According to Lundegärdh, growth and development of the plants are primarily dependent upon the inner concentration and distribution of the nutritive elements. From results of his study with oats he suggests that the ash of the leaves, within certain limits, will reflect the nutritive condition of the whole plant. He concludes that growth will cease when the concentration of any of a number of elements (especially potassium, calcium, phosphorus, and probably manganese and iron) in the leaves falls below a certain minimum.

The object of plant analysis, in addition to determining the nutrient requirement of a crop, has been in many instances based on a determination of the supplying power of the soil for available nutrients. Since it has often been found that the soil does to a large extent influence the composition of a plant growing upon it, the attempts to evaluate soil fertility with plant analysis does not seem entirely illogical. However, results obtained by many investigators have indicated that the nutrient content of a plant does not always necessarily reflect the supplying power of the soil. Thus, a soil deficiency of one element may result in a high level of another element appearing in a plant grown on that soil. This may not, however, indicate a high level of fertility of the latter element in that soil. Again, a low nutrient level may exist in the plant which may not correlate with a corresponding low, soil nutrient availability. Nitrogen is one element which may behave with such characteristic inconsistency. This fact has again indicated the necessity of placing greater emphasis on looking to plant analysis as a means of determining the nutrient requirement rather than as a medium of estimating soil fertility at least for nitrogen.

Macy (12) apparently has demonstrated the successful application of plant analysis to this phase of the nutrient requirement problem of plants. From his studies of the results of a number of investigators on plant growth, fertilization and nutrient content of plant materials produced, and from his own experiments with barley, Macy has advanced a theory on the relationship existing between the percentage content of a nutrient in a plant and the sufficiency of the nutrient for growth. This theory has been proposed for application in a method to determine the mineral nutrient requirement of plants by plant analysis. The dominant concept of this theory, as proposed by Macy, is a critical percentage of each nutrient in each kind of plant, above which there is *luxury consumption* and below which there is poverty adjustment which proceeds until a minimum level is reached.

During the period of poverty adjustment, growth takes place according to Mitscherlich's law of minimum and a factor may be only partially limiting because

of the compensating effect of other factors which may prove more favorable. Above the critical percentage (luxury consumption) or during the period of minimum level, Liebig's law of growth is in effect, which holds that the yield is directly proportional to the supply of the nutrient. While admitting that the percentage content of a nutrient in the plant may be affected by other growth factors, Macy points out that under the circumstances the sufficiency of the nutrient, as measured by the response to it, is likewise affected so that the relationship still holds. However, it was indicated that the critical and minimum percentages of nutrients in plants are not rigidly set, but may fluctuate because of the association of elements; one may reduce the effectiveness of another or may partly substitute for another. For instance, it was pointed out that the critical percentage of phosphorus may be raised by the presence of larger than normal quantities of aluminum in the plant.

In order to test the theory of sufficiency in fertilization, Macy conducted pot experiments growing barley in different soils and using fertilizer treatments with varying increments of nitrogen. Yield data for different increments of nitrogen were obtained and the plant materials produced were analyzed for total nitrogen. The yield data showed very large effects of treatments and of soils. While a wide variation occurred in the absolute yields, the relationship between the percentage nitrogen content of the straw and its response to nitrogen was independent of other variable factors. Thus, while the yield data for one treatment were definitely different from another, the points indicating the relationship between per cent nitrogen content and the straw of barley produced fell within a narrow curve and did not vary in excess of twice the probable error for a single point. The critical percentage determined by Macy for barley was 0.8 per cent nitrogen, and the minimum percentage about 0.4 per cent. Additional data were cited on the percentages for many plants determined by others which were comparable to Macy's critical percentage. These data follow: Wolff found 1 per cent nitrogen for the oat plant and 0.35 per cent P_2O_5; similar nitrogen levels for oats were apparent from results of Pfeffer, et al; Fraps, studying corn grown in pots, reported that 82 per cent of the crops having more than 0.70 per cent nitrogen responded to N less than 10 grams per pot, while 82 per cent of the crops having less than 0.70 per cent nitrogen responded to nitrogen more than 10 grams per pot; the sulfur content of alfalfa was indicated by Alway to be 0.2 per cent S; Garner obtained preliminary data indicating the same value for sulfur in tobacco; and Garner, et al, reported a tentative critical percentage of 1.5 per cent N in tobacco leaves.

Development of the Procedure:

Having considered briefly the theories advanced by other workers to determine the nutrient requirement of plants by analysis of their tissues, it is proposed to ascertain whether they are applicable to the method of leaf-punch analysis in controlling nitrogen fertilization of sugar cane. From a preliminary study it appears that the concept of critical and minimum percentages may be applied to leaf-punch analyses performed over intervals during the growth of the crop and a practical method of control may thus be formulated.

The data for yield and nitrogen content in Macy's calculations are obtained upon maturity of the crop grown with different increments of nitrogen. In the proposed R.C.M. leaf-punch procedure, the nitrogen values are obtained at pro-

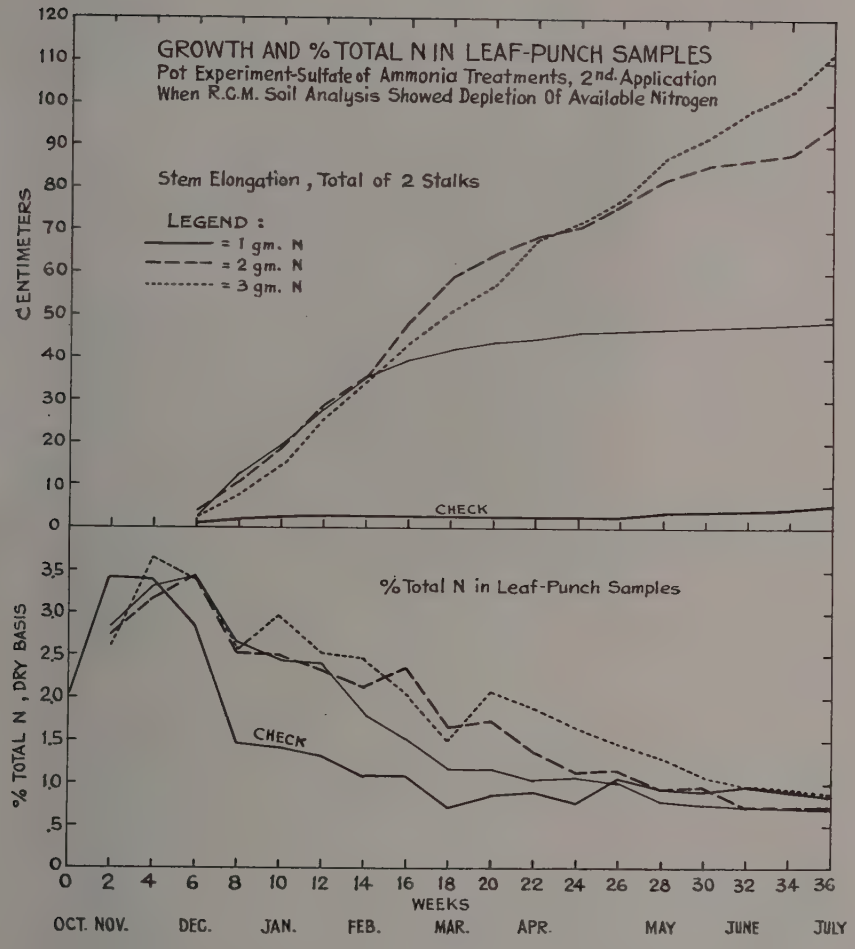

Fig. 11

gressive periods of growth. Thus, while Macy's data are obtained for a single period, the method herein proposed furnishes data for a successive number of periods. The interpretations placed upon both systems as to sufficiency, however, are comparable since their derivation comes from a common basis, that is, based upon the response of the plant to the fertilizer applied.

Reviewing briefly the relationship between nitrogen content of sugar cane leaves and the growth of cane as previously discussed, it may be restated that apparently, at least for H 109 cane, there *is* such a positive correlation. The data for pot culture of H 109 fertilized with sulfate of ammonia are summarized graphically in Fig. 11. The levels tentatively established from the study are, critical percentage 2.0 per cent, minimum percentage 1.0 per cent, and poverty adjustment between 2 and 1 per cent.

The object of the control is to maintain a balance in growth so that the excessive vegetative activity may not be too prolonged during the development of

sugar cane from start to harvest. Vigorous vegetative activity is generally believed to favor sugar consumption rather than sugar accumulation. Its regulation, therefore, appears to be the desirable approach in detemining the proper nitrogen requirement of the crop.

Trends in the rate of elongation of stalks are apparent from a study of the growth curves for a number of sugar cane crops grown under Hawaiian conditions. Weather and sufficiency of nutrient supply considered, it may be reasonably expected that in general the rates apparently characterize three stages of growth which become readily recognized. First, during the initial development of the crop, growth occurs slowly. Fertilizers are applied during this period. The nitrogen content of the foliage at this stage becomes rather high. With fuller development of the plant, the rate of growth gradually increases until a period occurs in which the rate of elongation has increased to a maximum and growth is rapid. This is the step which is generally recognized as the "boom stage" of growth for sugar cane. Usually, as expected under the established general fertilization practice, first-season nitrogen applications will have been completed within the early part of this boom stage of development. Sometime within this period a point will be reached where the rate of growth will be increased relatively greater than the rate of nitrogen absorption so that as elaboration proceeds the percentage of nitrogen in the plant will begin to decrease. As the nitrogen supply diminishes and as the meteorological factors become limiting, the rate of growth will gradually become retarded so that in the final stage of the crop cycle elongation gradually slackens and proceeds slowly or may cease entirely.

In the earlier discussions it was indicated that nitrogen fertilization may affect the percentage content of this nutrient in the sugar cane leaf and there is an apparent relationship between the percentages determined and the development of the plant. The proposed fertilization control, therefore, may be maintained, it seems, by regulating the nitrogen level throughout the cycle of crop growth. The initial development of the crop is planned to start and continue with a nitrogen level in the leaf close to the critical percentage. The growth at boom stage and throughout the period of accelerated elongation is to occur concurrently with the gradual lowering of the nitrogen percentage which will be in line with the poverty adjustment discussed previously. The final ripening will then take place as the minimum level of this nutrient is reached. The usual crop length under Hawaiian practice is about twenty-four months from start to harvest. The problem then is to space this interval so that a sufficient period is given to develop a good start, followed with an interval of vigorous vegetative growth and ending with a progressively decreasing rate of elongation and development in order that sufficient time for ripening may be allowed.

From a study of numerous field leaf nitrogen data, the results appear to indicate that the levels established below may meet the requirement of a 24-month crop:

Level	At age
2.0%	6-8 months
1.5%	12-14 months
1.25%	15-17 months
1.1%	24 months

Considering the usual practice of applying nitrogen fertilization in quantities sufficient for a 24-month crop, the results at hand indicate that during the initial period of growth it may be necessary to maintain the nitrogen level at about the critical percentage (2 per cent) for about six months from the start of the crop. This is to insure the proper development of the plant, that is, apparently nitrogen in excess of current requirement is required in order that tillering may occur early. If only a minimum supply of nitrogen is present, it may be possible that only the primary stalks will grow without much development of suckers. Hence, under a minimum supply of nitrogen, the quantity of growth upon maturity may be insufficient. Therefore, the critical level perhaps should be maintained for a period of about six months. Since it has been indicated that the level above 2 per cent is approaching the luxury consumption status, the level does not appear to be required, at such times, much above 2 per cent, except that during the first two or three months of growth following planting or ratooning the level may be higher than 2 per cent and it usually is (approximately 2.5 per cent, more or less) for this stage of growth.

After this initial development at about the critical limit, it is believed that the percentage should drop, commencing with and during the boom stage of growth. At this period "poverty adjustment" should set in. It has been shown previously that the interval in which the poverty adjustment operates, that is, the drop from the critical to the minimum percentage, will depend upon the nitrogen supply and the assimilation of nitrogen resulting from development and growth. Hence, if the nitrogen supply is excessive, the interval of the critical percentage will be maintained for a period much longer than six months and the time required to complete the poverty adjustment will be prolonged. The results of this study appear to indicate that if the nitrogen supply is not excessive growth should proceed so that the level drops gradually after the initial period from 2 per cent to 1.25 per cent upon reaching ages of 15 to 17 months. It has been shown in the growth studies previously described that elongation will not be retarded if the nitrogen level drops to 1.5 per cent or even as low as 1.3 per cent. If the level is maintained at 1.5 per cent, or above, for a considerably longer period than was indicated (a result, apparently, of the crop being over-fertilized, as has been shown to be possible) the conditions for vegetative growth are then maintained above normal for the corresponding age of cane. This may result in delayed or insufficient ripening before the 24-month harvest.

Further growth after the 15- to 17-month period may deplete the nitrogen supply in the plant so that the level will continue to drop. This should enable the plant to undergo a favorable and sufficient period of ripening which would favor its reaching the minimum N level of about 1 per cent at 24 months.

A form has been developed for recording the leaf-punch nitrogen data obtained in this type of study. It is illustrated in Fig. 12. Spaces are provided for data pertinent to field, crop and fertilization. Tabular columns are included for recording date of sampling, age of cane at sampling, growth measurement data if taken, the nitrogen index values and remarks. At the bottom of the page a form is appended for plotting a graphical presentation of the nitrogen data. The nitrogen percentages are placed on the ordinate and the age in months on the abscissa. In this graph, emphasized by heavy rulings, are shown the limits discussed above so

Field Variety Fert. N

Acres Crop P_2O_5

Sta. No. K_2O

Date Spld.	Age Spld.	Growth Measurements						N - Index		Average	

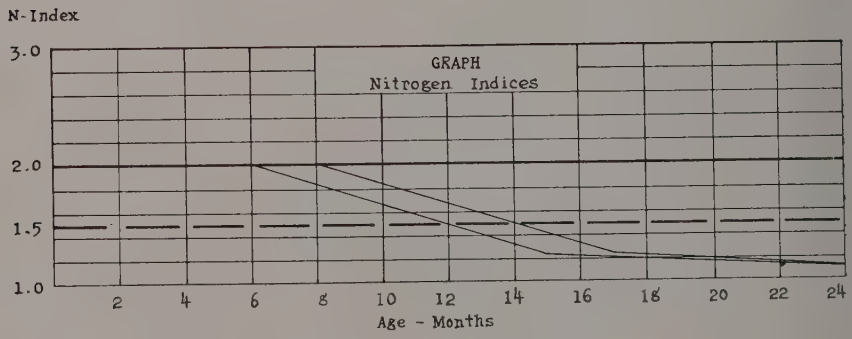

Fig. 12

that the trend and concentration of the nitrogen supply may be observed from the graph at a glance.

The limits of nitrogen variation in cane leaves for a 24-month crop have been discussed. However, some crops are grown for shorter periods, usually between 14 to 18 months. Since the growing period is thus shortened, and in order to provide a period of sufficient duration for ripening, the program of fertilization should be modified. However, in order to insure a proper development of the stool at the start of the crop, it may be found expedient to decrease the amount of nitrogen applied only to such an extent which will still insure a maintenance of the critical percentage up to the ages between 4 and 6 months. Sufficient data of this order have not been accumulated to justify a recommendation of fertilization establishing even tentative limits for the short crop. However, as a suggestive basis and in lieu of further study of the needs for this type of crop, limits of nitrogen levels which may be found appropriate are offered below:

N level	At age of cane
2.0%	4-6 months
1.5%	8-10 months
1.25%	10 months, lower limit
1.25%	18 months, upper limit

The method to control nitrogen fertilization of sugar cane by analysis of leaf-punch samples will now be summarized briefly. The system consists of a plant nitrogen study, followed through from start to harvest. Leaf-punch samples are taken at regular and progressive intervals and analyzed for total nitrogen. First sampling is usually started with 3-month cane and continues at about monthly intervals up to harvest. The results obtained are designated as the "nitrogen index" of the plant at a given age. These indices do not represent the exact quantity of nitrogen in the general leaf system or the entire plant but serve only, it is believed, as indicators of plant performance. Their interpretation with respect to nitrogen index limits proposed for cane of different ages may serve to indicate whether the nitrogen supply is sufficient, deficient, or in excess at the moment of sampling. The analytical data are recorded numerically and graphically. In the form of a graph, the points representing nitrogen index at progressive periods of growth form a curve upon which are superimposed the limits of the significant nitrogen levels previously discussed. The crop nitrogen situation, if plotted on the prescribed graph, is therefore available to the observer in a rather simplified and yet comprehensive form.

Practical Applications

Application With Respect to Preharvest Samples:

While studied primarily for fertilization control of a crop by following it from start to harvest, the method may offer possibility of obtaining further information of value in preharvest sampling as it is now conducted by several plantations. A tabulation of data from regularly harvested plantation fields is presented

TABLE X

ANALYSIS OF LEAF-PUNCH SAMPLES OBTAINED FROM CANE PRIOR TO HARVEST AND AT HARVEST. FIELD, ANALYTICAL AND YIELD DATA ARE TABULATED.

Field data				Nitrogen indices of samples taken, months before harvest				Yield data			
Plantation	Field	Variety	Lbs. N applied per acre	3	2	1	At harvest	Age at harvest	TCPA	TSPA	TC/TS*
"A"	K7B	H 109	230	1.75	1.68	1.60	1.50	19½	83.60	9.72	8.60
"A"	O-1B	H 109	236	1.58	1.56	1.57	1.55	21	83.83	9.52	8.81
"A"	O-7	H 109	238	1.35	1.48	1.41	1.28	22	89.82	10.81	8.31
"A"	G11	H 109	217			1.55	1.39	18½	71.16	8.45	8.43
"A"	P-1	H 109				1.49		18	71.74	7.57	9.47
"A"	O-16	27-8101	240				1.72	16½	94.63	9.61	9.85

Field data				Nitrogen indices of samples taken, months before harvest				Yield data			
Plantation	Field	Variety	Lbs. N applied per acre	3	2	1	At harvest	Age at harvest	TCPA	TSPA	QR*
"B"	30B	H 109	253		1.56	1.43	1.26	22	62.85	7.20	9.13
"B"	2A-3D	H 109	254	1.71			1.42	17	89.95	10.23	9.78
"B"	6	H 109	206		1.51		1.48	18	92.93	10.74	9.21
"B"	10C	H 109	250		1.42		1.47	21	89.62	9.70	10.04
"B"	21B	H 109	248	1.66		1.56	1.48	22	75.33	8.60	9.94
"B"	15A	H 109	237				1.28	22	105.76	12.74	8.30

* For Plantation "A"—Tons cane per ton sugar (TC/TS) are reported in place of the quality ratio (QR).
For Plantation "B"—The regular quality ratio (QR) data are presented.

in Table X. The relatively few cases of this type which have been studied do not warrant the assumption of conclusions which are necessarily significant. However, the generally poor juice qualities noted for some crops may appear to be correlated with the higher nitrogen percentages found in the corresponding leaf samples collected at harvest. The leaf-punch nitrogen results obtained at harvest having indices of about 1.5 per cent may be considered high insofar as they indicate a relatively ample sufficiency of nitrogen available to the crop to support further vegetative growth. The relationship between ripeness and quality of cane is not a subject the authors are qualified to include within the scope of this paper. The data are presented as such for suggested further study. It may be found that if preharvest data are to be rigidly interpreted, a single nitrogen value taken only at the time of harvest may not be found as valuable as a number of nitrogen indices determined at regular intervals prior to harvest. Preharvest sampling so far as leaf nitrogen studies are concerned should preferably commence just prior to the cessation of irrigation and continue at intervals through ripening until the time of harvesting.

Application in Control of Fertilization—A Tentative Procedure:

A few cases will be cited to illustrate possibilities of the practical application of the method in nitrogen control. Certain conclusions drawn from the experimental work of this study and a few accepted generalizations resulting from practical experiences of many local workers in sugar cane culture will be presented preparatory to the discussion on applications. First, it may be stated that the method here proposed does not directly control the quality of the cane produced. The type of study and the results obtained do not warrant any conclusions as to the relation of nitrogen percentages or growth to quality. Their relationship, if apparent in this study, has been noted only as an indirect observation. This method is designed for controlling the nitrogen *levels* in the cane leaf system because the variability of these levels appears to be associated with growth, that is, elongation of the stalk or the persistence of vegetative activity. The levels suggest a relationship bearing upon the sufficiency of the growth factor. In this study it has been assumed that the nutrients other than nitrogen have been supplied to or are present in the soil in amounts sufficient to insure that nitrogen only is the limiting nutrient. Second, it has been found that most Hawaiian soils planted to sugar cane will respond to nitrogen fertilization. A lack of response has been reported in only a few exceptional instances. (The amount of nitrogen required per crop may, however, vary with the variety from crop to crop and from locality to locality. In general, response has been realized up to applications of 150 pounds of nitrogen per acre, but very little economic response is reported where the application equals or exceeds 300 pounds nitrogen per acre.)

Assuming that a field of cane is to be fertilized and that the previous crop did not show a substantial gain when receiving over 150 pounds of nitrogen, then, for the first application an amount may be applied which will be *less* than the 150 pounds required for the previous crop. The quantity needed is split into a number of applications, or the entire amount is applied initially, depending upon the practice in vogue at the plantation. Commencing with the age of three months, or earlier, if the development of the shoots permit earlier sampling, the first leaf-punch

samples are collected and this practice continued periodically thereafter at regular intervals. The results obtained are recorded numerically and graphically on the forms provided for that purpose. The data determined at each sampling with reference to its index of sufficiency as compared with the theoretical curve will suggest whether additional nitrogen may or may not be applied. The quantity of nitrogen to be applied will depend upon (a) previous requirement of the crop, (b) the age of the present crop, (c) the nutrient level as to sufficiency, (d) the time of the year, (e) the total quantity applied to date, and (f) the final total which will be reached with the addition of the current increment. In the unirrigated plantation, it may be of advantage also to determine available soil nitrogen. The above brief discussion illustrates, in general, the procedure which may be followed in applying leaf-punch nitrogen analyses to nitrogen fertilization control. Until a much wider experience is gained in the field, the suggested procedure of study can scarcely be made more specific.

A hypothetical case is presented to demonstrate the practical application of this system. Referring to Fig. 10, data have been plotted from the results of the experiment where 250 pounds of nitrogen were added in a single application to a plot of cane at the age of 1½ months. The crop was planted in June. The analytical data indicated that at the age of 3 months the nitrogen level was down to 2 per cent (by inspection) and at the age of 4 months it had dropped to 1.7 per cent. Considering the theoretical nitrogen limits for the cane, the percentage of this nutrient determined indicated an apparent need for nitrogen at this point. It now becomes a question as to whether more nitrogen should or should not be applied. A suggested first step would be to resample the cane leaves to learn if the value of 1.7 per cent was correct. Having checked this finding, the soil may be analyzed to determine the supply of nitrogen available to the crop. Assuming that analysis showed depletion of available soil nitrogen and that the stand of cane appeared normal, vigorous and well developed, the investigator may then conclude that in view of the low nitrogen level in this young cane, assuming that fair growing weather prevails, further fertilization is in order. The decision having been made to apply nitrogen, it becomes necessary to decide on the quantity to add. From past experience one may realize that cane in this general area did not respond to nitrogen applications above 250 pounds. Knowing that in general this amount represents nearly the upper limit of applied nitrogen with most cane areas, it may therefore appear as unwise to increase the application by 60 or 75 pounds more and thereby bring the total applied in excess of 300 pounds. Therefore, let it be assumed that 50 pounds additional nitrogen are applied. If the subsequent cane leaf analysis two months later shows a still lower level, say 1.4 per cent at 6 months, the question of additional fertilization will again have to be considered.

Based upon the interpretation of the data alone as to sufficiency for a 6 months' crop, the leaf nitrogen at 1.4 per cent will appear to indicate a need for this nutrient. However, other factors will have to be considered, as pointed out previously. One of them is the final total quantity which will be reached if further increments are to be added. Since the quantity of nitrogen added to date has totalled 300 pounds and the optimum for previous crops was believed to be 250 pounds, any additional application will require careful consideration. It was previously discussed in the relationship of nitrogen levels to growth that 1 per cent is the mini-

mum level in which growth will be retarded. Also, it was indicated that at 1.3 per cent growth will not be limited if weather is optimum. The level of 1.4 per cent, therefore, while unusually low as far as being best for the initial development of the crop, need not be considered as absolutely limiting. The cane is 6 months old in December. Hence, growing weather for the following two or three months may be assumed in perspective as being not optimum, based upon the usual winter seasonal behavior. All factors considered, therefore, the decision may rightly be made to leave off fertilization for the next two months.

The level at 8 months still shows a nitrogen index of 1.4 per cent. If a deficiency had then existed, growth and elaboration during the previous two months should have lowered the level. Since the level did not drop in this interim but remained at 1.4 per cent, it seems in order at 8 months to still delay further application for another two months of cold weather. After this interval it is expected that better growing conditions will have set in. Fertilization made at that time will be in line with the customary second-season practice and is therefore not too late. However, from the tenth month on, the level rose and followed the theoretical limits closely up to the age of eighteen months, when further leaf collections were discontinued. Results of the actual experiment support the decisions made in the hypothetical case. Treatments of 100 pounds and 400 pounds were made in addition to one supplying 250 pounds nitrogen in the actual test. The growth data (both elongation and increase in dry matter per stalk) seem to indicate that the 250-pound application was the optimum. The 300 pounds made in theoretical applications to the hypothetical case appear sufficient and yet not excessive. The quantity is practically close to the optimum.

Consider next an actual case illustrated in Fig. 13. In this field of H 109 cane the initial amount of 50 pounds was applied to a plant crop at the age of 1½ months. Leaf-punch analyses within an interval of 2 months after fertilization showed the nitrogen level to have dropped from a high of 2.4 per cent to 1.95 per cent. An additional 50 pounds were applied. Subsequent analyses showed a drop to 1.74 per cent at the age of 5 months, indicating a necessity for further fertilization. Fifty pounds more were applied. This addition raised the level to 2.07 per cent at the age of 6½ months and two weeks later dropped to 1.92 per cent. According to the proposed limits further fertilization for the time being was not necessary, but a contingency in the cultural practice for this field required an additional 75 pounds. Samples taken for the next two months indicated that the additional 75 pounds had created an excess. The requirement for this particular crop, according to interpretation of analytical data, apparently should be between 150 to 175 pounds.

In the other half of the same chart is illustrated the requirement for POJ 2878 cane grown in the same field and under identical conditions. The nitrogen curve for this variety indicated that the 225 pounds were sufficient for the crop up to the ninth month. Up to this period the curve, while slightly low for the first period of growth, followed closely the theoretical limits. The points on this curve, while below 2 per cent, were still higher than 1.5 per cent. Since 1.5 per cent is not deficient for normal growth, it may be assumed that the curve is satisfactory. The curve continued to drop below the arbitrary limits at the ages of 10 and 11 months, the nitrogen index at 11 months being slightly below the 1.5 per cent

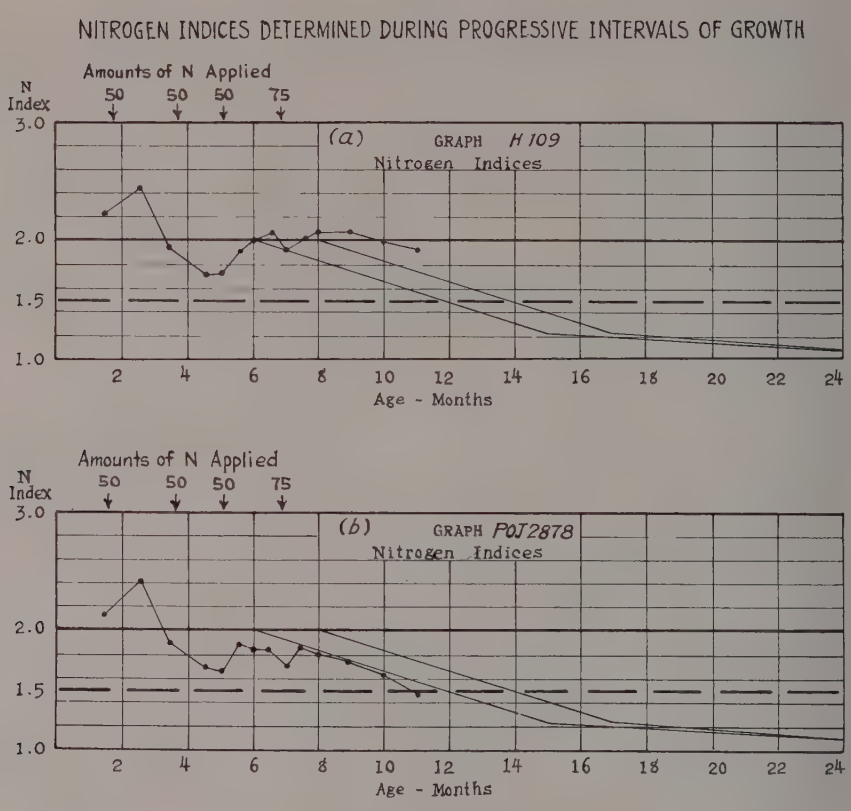

Fig. 13

level. According to the proposed limits, second-season applications of nitrogen may be made if the crop is to be grown for a 24-month period. Additional field data illustrating trends obtained in practical application are presented in Fig. 14.

It is to be hoped that with this method there will be placed in the agriculturist's hands an additional instrument which may aid him in putting nitrogen fertilization upon a more nearly rational basis of field control. During the course of this investigation a large number of Grade "A" amounts-of-nitrogen experiments were studied. The results appear to indicate that in many of these experiments the field practice applications exceeded the optimum requirement by as much as 50 to 100 pounds of nitrogen—equivalent to 250 to 500 pounds of sulfate of ammonia fertilizer. These excesses were in many instances not only for one crop, but were shown to exist in the preceding one or two crops. In spite of this, for lack of a means or method which will evaluate the variable requirement of a crop, the large applications rather than the indicated optimum have been maintained more or less as precautionary measures. With the tentative procedure outlined, it is possible to obtain from a growing crop data which may be measured against tentative standards to determine the assimilation of nitrogen or its relative sufficiency. These data will offer an additional guide which the agriculturist may consider in arriving at a decision on crop nitrogen requirements.

NITROGEN INDICES DETERMINED DURING PROGRESSIVE INTERVALS OF GROWTH

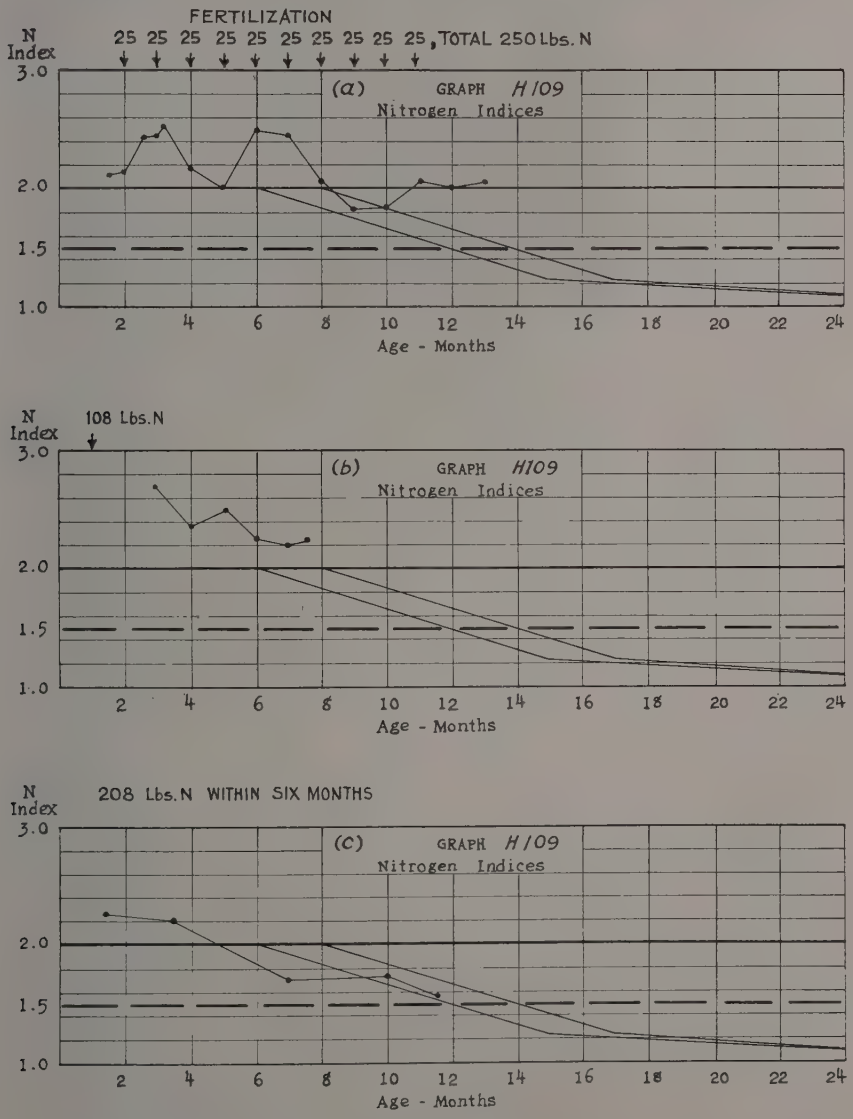

Fig. 14

Summary

Sugar yields in Hawaiian production in recent years have indicated the necessity for closer control of nitrogen fertilization. The determination of *available* nitrogen by soil analysis has been found to possess only limited application in crop fertilization control of nitrogen. Complicating the problem is the changing requirement of the crop for nitrogen as influenced by weather. These factors have pointed to a desirability of learning from the plant itself its needs for nitrogen.

The possibility of using the plant leaf system as an index of its nitrogen needs was explored with a rapid chemical method developed at this Experiment Station. A standardized procedure for obtaining leaf-punch samples from definitely localized points in the leaf system for nitrogen analysis was established through the auspices and active participation of Mr. Agee. The results indicated that the leaves designated by the second, third and fourth dewlap (ligule) attachments gave the most consistently satisfactory results. The uppermost visible dewlap is counted as one. The particular section of the leaf to be sampled has been found to exist in a region midway of the blade from either end at its widest point. The procedure consists in sampling definite grouping of leaves, but with random selection of stalks. Two sampling stations are established for each field. Two disks are removed from each sampled leaf and sixty leaf disks constitute a sample. One sample is taken from each station. Repeated checks with this procedure have indicated that where growth in a field is uniform, the results obtained for the two stations are nearly always in very close analytical agreement. This apparent uniformity of nitrogen and plant relationship within a field, the simple system of leaf sampling, and precision of analysis have established a foundation which, it is hoped, may be found suitable for purposes of establishing a satisfactory field control.

A pot experiment was conducted wherein a relationship was found to exist between the nitrogen content of the leaf samples and elongation of the stalk. The method of determining nitrogen index in the cane plant, as described in this paper, was applied to a number of field surveys from which it was determined that the nitrogen content of the field samples were within the same range as those determined in potted cane. A study of growth data of field and potted canes indicated that there is also a similarity in the relationship between fluctuation of nitrogen content in the leaf system at periodic intervals and growth of sugar cane in the corresponding intervals.

A study of the data indicates that apparently a critical nitrogen percentage in the leaf-punch sample may be established, above which a state of luxury consumption is indicated. The optimum nitrogen index lies between the critical high point and a minimum value, below which growth as measured by the elongaton of stalk is negligible. When the nitrogen data, termed as "nitrogen index" values, are plotted with the indices on the Y-axis and the monthly intervals of collection on the X-axis, the resulting curve will provide a graph showing the progress of the nitrogen situation in the entire crop. Under normal conditions, this curve can be influenced readily by fertilization and advantageously so at several intervals of growth.

From results of this study, levels or limits of the nitrogen content of the leaf-punch samples have been tentatively prescribed for a 24-month crop of cane. It is proposed to interpret the leaf nitrogen data with respect to the sufficiency of the

nutrient for the crop throughout its growth cycle. These limits and interpretations are incorporated into a tentative method for the control of nitrogen fertilization. In brief the control may be achieved by collecting leaf-punch samples at progressive intervals, obtaining their total nitrogen content (nitrogen indices) by analysis with a rapid chemical method and determining the need of the crop for nitrogen from a study of the plotted data. Practical applications are discussed and illustrated with data presented graphically.

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Dead Cane at Harvest

By J. P. Martin

The subject of dead cane at harvest has been investigated on different occasions, but more recently it has been brought up by H. P. Agee for further consideration. The object of this paper is to present and briefly discuss those factors responsible for dead cane at harvest, a number of which have been suggested by persons interested in the general subject. It is hoped that this article will stimulate a wider interest in this important phase of sugar cane culture and that contributions from others will be received.

Little difficulty is experienced in maintaining an accurate record of all existing conditions in a cane field from the time sugar cane is planted until it begins to lodge. However, once the cane has become lodged, especially with the heavy tonnages which result in a thick blanket of cane and trash, it becomes most difficult to record accurately the conditions within a field, many of which are harmful and become apparent only at harvest.

The age of cane at harvest is usually between 14 and 24 months, although in some instances the age may be less than 14 months or more than 24 months. The environment, variety, field culture, economic conditions, pests, and diseases are some of the major factors which govern the age of cane at harvest and which are responsible for a certain amount of dead cane. It is not uncommon to observe dead cane at harvest; at times the amount present causes a marked reduction in yields, again in some fields little or no dead cane occurs. Dead cane is more apparent where the crop is hand cut than where it is mechanically harvested.

If one is cognizant of existing environmental conditions during the growth of a field and aware of the factors which cause cane to die prior to harvest he is in a much better position to render a satisfactory explanation of the problem. With such a knowledge it may be possible to adopt and carry out definite measures for maintaining conditions favorable to the development of the cane plant and thus reduce monetary losses.

It might be desirable to consider the individual stalk as the unit in a field rather than the stool since field observations at harvest have shown that it is the aggregate of individual stalks that makes up the major portion of dead cane. Under some circumstances two or more dead stalks may occur in a stool but seldom does the entire stool die. A careful examination of those dead stalks which are found at harvest has, in the majority of cases, shown that the stalks made a normal growth for a certain period as evidenced by the length and diameter of internodes and total stalk length. Often these growth indices, when studied in relation to mature cane, aid in establishing approximately the time the stalks died. For example, short, medium, or long, dead stalks would indicate that such stalks had died during the early, middle, or latter part of the crop, respectively.

Environment:

The environment includes "all the external conditions and influences affecting the life and development of an organism." We may think of the environment of the cane plant as being made up of the climatic and soil factors. The climate is determined by such factors as light, temperature, rainfall, humidity, and wind. In considering the soil we must think of the physical factors, namely, texture, structure, tilth, depth, aeration, moisture retention, drainage, etc., and the chemical factors such as soil acidity, and the chemical composition of the soil and of the soil solution. All of the above factors govern to a large extent the physiological processes taking place within the plant; any one factor if unfavorable to the plant may retard its growth and cause it to die before reaching maturity.

In order to appreciate the effect of climate on cane growth one has only to go from the lower to the higher elevations on any plantation. Possibly the two climatic factors most responsible for the heavier yields at the lower elevations are increased sunlight and higher temperatures.

We realize that the total number of shoots which start in a plant or a ratoon field never reach maturity. R. J. Borden called the writer's attention to some very interesting data on stalk mortality in unpublished studies which he and F. C. Denison conducted in 1930 and 1931 with H 109 and POJ 2878 at Waipio Substation. The average per cent mortality of cane stalks at different periods from seven plots (each plot .0861 acre in size) of each variety and treatment, as determined by stalk counts follows:

Variety	Between 2nd and 5th months	Between 5th and 9th months	In first 9 months	Between 9 months and harvest	Stalks counted at 2 months which failed to survive until harvest
H 109*	13.1±7.8	10.1±3.0	22.1±6.5	22.6±3.8	39.5±5.8
POJ 2878*	21.9±9.7	8.5±2.2	28.7±8.4	7.1±3.3	31.9±8.5
H 109†	30.5±4.5	14.9±3.1	41.1±1.8	25.4±6.1	56.7±3.8
POJ 2878†	37.5±8.1	16.6±2.0	48.1±5.9	17.3±4.0	56.7±6.5

* Cane planted in standard furrows, 5 feet apart.

† Cane planted in borders 10 feet wide, rows 3.3 feet apart.

In more recent studies Mr. Borden offers the following figures regarding stalk mortality in 31-1389, plant cane, Field 19, Makiki Station:

SHOOTS PER FOOT OF CANE LINE
(Planted April 13, 1937)

July 30	August 30	May 1, 1938 at harvest
10.6	5.9	4.6

From the above figures it is very apparent that a high mortality of cane stalks occurs shortly after the cane begins to close in, partly as a result of reduced light—the shoots having been "shaded out." A certain amount of this mortality is probably due to competition and crowding of stalks within the stool. The death of the young shoots at this period of growth is not greatly reflected at harvest merely because an acre of land can only support or accommodate, depending on the variety, in the neighborhood of some 30,000 or 40,000 mature stalks. During the growth of a crop dead stalks are observed where cane has become lodged by wind, by the

practice of pushing back, or as the result of its own weight, and the only apparent cause of death is reduced light or a shading out of the growing top; dead cane from this cause cannot be diagnosed at harvest.

It is not uncommon to come upon depressed cane growth or even dead cane in regions exposed to long periods of severe drought or in localized areas of excessive soil moisture. These adverse conditions may occur at any time before the crop reaches maturity. In regions of heavy rainfall, conditions are favorable for the development of various stalk rots which result in a certain amount of stalk deterioration; under dry conditions these rots are less active.

Light showers and high relative humidities are not responsible for dead cane but they do favor the rapid spread and development of eye spot disease which when severe often produces top rot; if the stalks manifesting top rot fail to send out side shoots or "lalas" they soon die. In fields so affected or where individual stalks scattered throughout the field have been killed, then an appreciable amount of dead cane at harvest can be expected.

During severe wind storms large areas of cane become flattened as though a large roller had passed over the fields; this condition is more pronounced when strong winds are accompanied or preceded by heavy rains. Cane stalks injured by wind frequently break near their base and may continue to live for several months. Strong winds may cause a sudden drying of the leaves or a breaking of the cane top near the growing-point region and in either case the stalk sometimes dies. During one wind storm the cane may be lodged in one direction and during the next storm, if the wind is from an opposite direction, the cane may be lifted and laid in a different direction; a sudden shifting of cane at any period of its development, but especially toward maturity, causes dead cane which at harvest cannot be easily explained. When wind damage is observed it might be advisable to mark such areas and attempt to measure the amount of dead cane at harvest. The brittleness of a variety has a direct bearing on the number of broken and dead stalks following a wind storm. A record of field conditions where portions of a field have suffered from wind damage might explain why more dead cane at harvest occurs only in certain parts of the field.

The physical and chemical factors of a soil may at times play a part in the problem of dead cane at harvest. We refer particularly to acute cases of excesses of soluble salts of sodium and magnesium in the soils, or deficiencies of one or more of the essential elements. Cane plants suffering from malnutrition usually manifest leaf or stalk symptoms by which such nutritional disturbances may be recognized. Possibly these factors, if unfavorable for cane, play a greater part in relation to depressed or abnormal growth than they do to dead cane at harvest.

Varieties:

Under a given set of environmental conditions the ripening period of one variety sometimes varies from that of another and the holding-over qualities may also vary. Yellow Caledonia, for example, after reaching maturity is able to retain its juice quality for a much longer period than D 1135. Early maturing varieties with poor holding-over qualities deteriorate rapidly and may develop a condition known as sour

rot, the final result of which causes the entire stalk to die. These factors are of considerable importance in relation to dead cane at harvest only when cane is held for some time after it reaches maturity.

The qualities of a variety, namely, hardness of rind, tasseling, size of stalk, rate of growth, erect habit, and secondary growth are of primary importance in relation to those factors producing injuries to the cane plant. Where the cane borer is a problem it is highly desirable to have a variety with a hard rind. Varieties that tassel freely but do not readily develop lalas are undesirable since tasseled stalks without lalas die. The size of stalk, rate of growth, and erect habit of a variety have a direct bearing as to the time cane begins to lodge. Heavy secondary growth, as produced by some varieties, covers and shades out a number of primary stalks which have become lodged with the result that the latter die prior to harvest. A splitting of internodes known as "growth cracks" develops in a few varieties; this condition is undesirable since it permits the entrance of organisms which may cause the stalks to sour or rot.

Field Culture:

A greater efficiency in supervision and irrigation has been obtained by the practice of "pushing back" cane along irrigation ditches. If the cane is pushed back at a time when the soil is wet and soft from rains or irrigations little or no damage to the plant results; however, if this practice is not carefully carried out considerable stalk and root injury takes place. In order to reduce stalk damage to a minimum the cane should be pushed back gradually, otherwise an abnormal amount of dead cane may be present along ditches when the field is harvested.

A small degree of damage to the cane plant occurs during various field operations, *viz.*, disking, cultivating, weeding, etc. In the early part of the crop these injuries are of little significance but they may permit the entrance of parasitic organisms which frequently cause a souring or rotting of the stalks. The tractors used for drawing mechanical implements in a field break and injure a considerable number of stalks.

Some injury to well-formed and mature stalks has been caused by chemical weed sprays. This is especially true along edges of fields where weed sprays are applied repeatedly and the spray comes in contact with the stalk. Usually the damage extends only a short distance within the stalk but in some instances practically all the stalk tissue at the base is killed and the stalk eventually dies.

In a harvested field where "high cutting" is in evidence a certain amount of dead cane can be expected when the field is again harvested. The primary shoots in a ratoon crop develop from the underground buds of the previous crop. The buds on exposed stubble or high-cut cane develop at first into what may be considered normal shoots. Later if such stalks are examined the point of attachment to the stubble will be found to be extremely weak and one can realize how easy it is for the stalk to break at this point. Furthermore it is difficult to "hill up" high-cut cane sufficiently to overcome this weakness. A careful study of individual dead stalks at harvest showed definitely that a number had developed from stubble of high-cut cane of the previous crop. These observations were made by following individual

dead stalks to the ground level where they were found to be broken but still attached to the exposed stubble. Similarly weak stands may come about (especially with varieties that lack vigorous ratooning properties) when overcast weather prevails at the start of a crop, or when weed growth shades the soil, so that the sun does not warm it to sufficient depth to bring about the sprouting of deeply placed eyes of the stubble. In consequence, there is reason to believe that the stand of cane is made up largely of shoots which developed from near the surface. Many of these surface shoots break off and die when the crop lodges.

Observations to date indicate that there is less dead cane in plant than in ratoon crops. In plant fields there is sufficient soil around the base of the plants for considerable mechanical support and the stalks are firmly attached to the underground portion of the stool, whereas in ratoon fields, especially with high-cut cane, the opposite conditions are frequently found.

A short-cropping system tends to make for less dead cane at harvest than a long-cropping practice simply because the cane after it has become lodged is exposed for a much shorter period to those detrimental factors, causing cane to die prior to harvest.

In some instances an insufficient amount of the necessary fertilizer may result in depressed cane yields but rarely does cane die from this cause. On the contrary, excessive fertilization with nitrogen tends to produce soft rank growth that is more susceptible to the hazards that cause dead cane. In a few specific localities where an acute deficiency of an element exists the cane may die before it reaches maturity unless the necessary element is made available for the plant.

The aim of all field cultural practices is to have the maximum number of mature stalks in a sound condition at harvest.

Economic Conditions:

The age of cane at harvest depends on a number of conditions, such as, climate, the variety, soil, irrigation, fluming water, fertilization, time of planting, cultural practices, pests, diseases, etc. In recent years certain economic conditions have made it impossible to harvest some fields at the optimum age with the result that an excessive amount of dead cane was present at harvest.

Insects:

C. E. Pemberton points out that the beetle borer, *Rhabdocnemis obscura* (Boisd.), prefers recumbent to standing cane and that its damage is more severe in long crops than in short crops. The runways or tunnels made by the grub of the beetle borer are often very extensive and they not only weaken the vitality of the stalk but may cause it to break. Red rot disease and a souring of the stalk by fermentative organisms often follow borer injury and contribute greatly to economic losses. The beetle borer is probably one of the factors causing cane to die before it reaches maturity. It is definitely known however to be attracted to and develop in dying or dead cane and its exact importance as a causative factor in the formation of dead stalks is not fully determined.

The grub of the Anomala bettle, *Anomala orientalis* (Waterh.), feeds on the underground portion of the cane plant and through its injuries parasitic fungi and bacteria sometimes invade the plant and produce a rotting or souring of the stalk. According to Mr. Pemberton a certain number of dead stalks may in some regions be attributed to Anomala injury followed by parasitic organisms; when 100 or more grubs appear in single stools, root pruning may be so severe that most of the stalks in the stool die.

In some instances soil-inhabiting animals, for example two species of nematodes, *Tylenchus similus* Cobb, and *Heterodera marioni* (Cornu), have produced considerable injury to cane roots and have been responsible for reduced cane growth and possibly have contributed toward an early death of cane stalks.

Diseases:

The leaf, leaf and stalk, stalk, and root diseases which sometimes cause cane to die prior to harvest are discussed separately.

Very few diseases attacking only the leaves actually cause the death of the plant. Of these diseases limestone chlorosis and Pahala blight when severe have been responsible in a few instances for the death of a small amount of cane.

The greatest amount of dead cane occurs from the leaf and stalk diseases which are given in their order of relative importance: eye spot, leaf scald, red rot, pokkah boeng, and red stripe.

The relation of eye spot to dead cane at harvest has been mentioned under *Field Culture*. It might be stated that eye spot in the last two decades has caused more cane to die before harvest than any other disease. Eye spot when present is most severe in low-lying areas where the cane is making a rapid growth and where conditions are as a rule more favorable for the other harmful factors.

The severity of leaf scald is governed to a large extent by existing environmental conditions and during epidemics of the disease cane is often killed outright. The greatest losses usually take place when cane growth is retarded as a result of low soil fertility, drought, or maturity. Cane killed by leaf scald can often be recognized at harvest by the presence of the numerous side shoots or lalas on the dead stalks.

Red rot brings about the death of many stalks; the red rot organism enters the stalk through animal, insect, chemical and mechanical injuries and at times losses are of major importance.

An occasional cane stalk has been killed by pokkah boeng but as a rule affected plants recover. In localities where red stripe is serious, top rot results and unless the lateral buds develop the affected stalks die from the effects of the disease. Red stripe is primarily a leaf disease but in some instances it affects the spindle, growing point and stalk. Pineapple disease has caused some losses in standing cane but such cases are rare.

The root diseases responsible for dead cane are *Pythium* and *Marasmius* root rot. Cane in a weakened condition may die from *Marasmius* root rot; the disease itself is considered of secondary importance inasmuch as it attacks cane that is in a poor growing condition. With the commercial varieties grown today *Pythium*

root rot is important only where malnutrition is a contributing factor; however, with varieties susceptible to *Pythium* root rot an excessive amount of dead cane at harvest can be anticipated.

Various Injuries:

Under this general heading some of the more important miscellaneous injuries to sugar cane should be mentioned.

We all fully appreciate the seriousness of the rat problem and the large economic losses resulting therefrom. The injured stalks are not only weakened in vigor but they often break at the point of injury and die. The large wounds caused by rats permit the entrance of pathogenic organisms which cause a rapid souring and rotting of the stalks. Rat injury is commonly found on dead cane when examined at harvest and is no doubt one of the largest contributing factors to this general problem.

Although of minor significance fire burn, leaf burn, and lightning injury are three elemental injuries which have caused cane to die in a few instances. Cane fields located close to the ocean are sometimes injured by salt spray and a small amount of cane has died from frequent exposures to salt spray.

Chemical injuries from fertilizers and weed sprays play a small part in the general subject; the latter has been discussed under *Field Culture*. Fertilizer burn is of more concern with young cane since practically all of the fertilizers are applied during the first half of the crop cycle.

In discussing the subject of dead cane at harvest Mr. Agee has submitted the following comments:

It may be said that while the importance of none of the specifically known causes are to be discounted in accounting for dead cane at harvest (such as wind, rats, borers, diseases, etc.) yet we must concede that apart from these there are death factors of high importance that are not sufficiently well understood. Self-shading or lack of sunlight due to lodging or to heavily overcast weather for a prolonged period no doubt play a prominent part in killing many stalks or in weakening them to a point where they easily succumb under the influence of other factors that contribute to their death.

A certain amount of dead cane at harvest is likely to come about inevitably with high cane tonnages. The life span of the individual stalk of cane will vary enormously under differences in environment and in accordance with varietal influences. Scores of cane varieties fail to find acceptance because stalk mortality is too high; the few varieties that do become commercial ones succeed because of a vitality that keeps so large a part of the stalks alive to the point of harvest. A variety that succeeds in one environment fails often in another largely because so many stalks die in advance of harvest. H 109, for instance, is a cane variety that thrives under conditions of high sunlight; stalk mortality is high if it is grown in areas of high rainfall and overcast skies. This variety, grown in areas that are only fairly well suited to it, is apt to show a high sensitiveness to climatic variations. In bright years it does well, in dull years it may do poorly.

As Dr. Mangelsdorf has pointed out, the conditions that permit of our high cane yields under long crops, 20 to 24 months, are rather special ones. In few places other than Hawaii do these conditions prevail.

In the warmer environment of Java, cane on lodging loses its sugar content rapidly and deteriorates badly. The stalks send out roots and lalas, many of them die.

The low lands of Oahu and Maui have the conditions of moderate heat and bright sunlight that are well suited to heavy cane yields under long crops, and these when we come to analyze it are conditions suitable to cane stalk longevity.

In other places, certain fields of windward Kauai and Kohala are examples, cane makes good growth the first twelve months, lodges and thereafter, probably through lack of the temperatures of the better irrigated lands, fails to make growth the second year in keeping with that of the first. It would seem, though we lack the specific knowledge we would like to have to support the theory, that when a field of cane lodges and the cane tops lose the positions they have held in the sunlight, a considerable amount of vegetative vigor is needed for the stalks to gain new positions that give them the light they need. Cane stalks reach for light and move into it by the wedge-like growth that takes place in meristematic tissue of each joint. By this means they bend in one way or another to find a place for their leaves in the sun.

Under a lack of temperature (or light) that induces the required vigor to bring about this adjustment of position effectively, self-shading, under the stress of lodging, probably becomes a potent factor in stalk mortality.

Consider that a plausible explanation rather than a proved fact, and it leads us to the point of saying that stalk mortality at harvest will be better understood when we have a better understanding of the whole gamut of environmental influences as they affect the crop as it grows to a heavy stand, as it thins down the number of young shoots by self-shading, as it inclines or lodges and readjusts itself as best it can to these trying circumstances, and as it continues growth to harvest.

The precise study of how the cane plant, as part of a cane crop, lives and grows, and thrives or dies, is a subject of inviting interest, and is furthermore one in which all of those who tend cane fields can participate, to the advantage, quite likely, of themselves and the industry as well.

Succinctly expressed we often know just why cane stalks die, but there are many occasions of high mortality where the death factors are surrounded with a great deal more mystery or uncertainty than we can be content to tolerate.

Acknowledgment:

The writer is indebted to Messrs. H. P. Agee, R. J. Borden, C. W. Carpenter, A. J. Mangelsdorf and C. E. Pemberton of this Station for their valuable contributions which have been included in this paper.

The Effects of Oven Drying and Air Drying on the Available Nitrogen Content of Soils

By P. E. Chu and Francis E. Hance

At the time a field crop of sugar cane is harvested the soil in the field, as a rule, is quite low in its concentration of "available" or readily soluble nitrogen. Immediately thereafter, however, upon exposure of the bare field to sunlight (warmth) and moisture, bacterial action appears to be stimulated and the formation of available nitrogen occurs from insoluble organic sources in the soil. Fukunaga and Dean (2) describe this process as "mineralization of nitrogen."

As a companion determination to the progressive sugar cane leaf-punch nitrogen field survey, an appraisal of the status of available soil nitrogen, at any given moment, is highly desirable. It is common knowledge, however, that by the time representative soil collections can be made, dried and composited for analysis a delay of ten days or longer will have ensued and the available nitrogen concentration will have been markedly changed. Either one of these conditions defeats the purpose of the determination.

Therefore an attempt has been made (a) to ascertain the shift in soil nitrogen availability as brought about by various methods of artificial and natural drying of the soil specimen, and (b) to develop a rapid method of measuring soil nitrogen availability with fair accuracy in the shortest possible space of time immediately following the sampling of the field soil.

As a general rule, soils intended for analysis are air dried before they are disintegrated, sieved, mixed and prepared for the analyst. Soils taken from the field may vary from saturation with moisture to a wetness below the wilting coefficient. On some plantations, or in localities of high humidity, air drying of some soils may require days or even weeks. Hence, if drying is an analytical prerequisite, rapidity of drying is a necessity unless other methods of making the determination be found.

Obvious methods of drying soil are to place the sample in an oven at controlled temperature or near sources of warmth in the sugar factory. We shall consider the extent of the changes, if any, that take place in the ammoniacal, nitrate and *total available* nitrogen content of soils when they are dried by various means and for different periods of time.

Russell and Petherbridge (7) found that the rate of decomposition of organic matter by bacteria and the formation of ammonia increases, with increased temperature, under moist conditions and reaches a maximum of about 45° C. Lyon and Bizzell (5) found that water-soluble nitrogen increases when soils are sterilized or are placed in the oven at 100° C.

Alexander (1), Lyon and Bizzell (5) and Webster (8) also reported that plants grow better in steamed soils after a certain period. Russell and Hutchinson (6) found that partial sterilization causes a fall in the number of soil bacteria and soon after an increase takes place, together with a rise in the ammoniacal fraction. Fukunaga and Dean (2) report that they note an initial rapid release of nitrogen apparently associated with microbiological decomposition of nitrogenous compounds when soils are incubated. This is followed by a second phase of slow release.

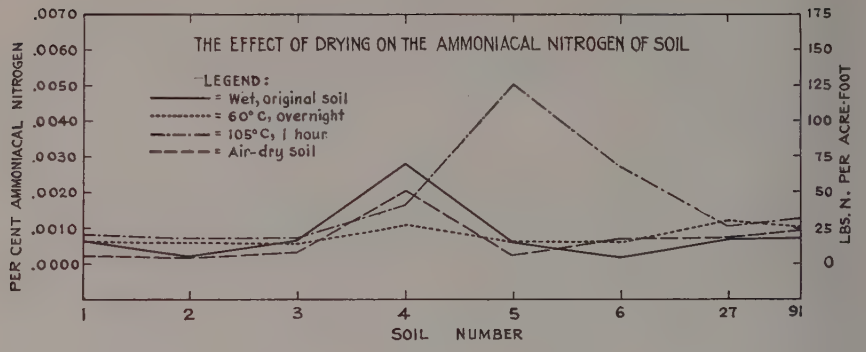

Fig. 1

Experimental

Temperatures were determined at which it was found possible to dry soils in a short time, say, between an hour and twenty-four hours. Analyses of the samples were made immediately after drying by means of the rapid chemical methods (3, 4). This procedure would indicate any increases of available nitrogen which may have developed due to heating and also it should show the extent of such changes as brought about by the heating.

Preliminary tests with soils Nos. 27 and 91 indicate that at 105° C. these samples were sufficiently dry to be workable in about one hour. At 60° C., twenty-four hours or longer are necessary to secure comparable drying. These two temperatures were therefore selected to produce what may be considered good indications of the changes which may take place in the available nitrogen of soils when so treated. For this purpose a representative number of soils were selected which are known to be difficult to dry.

In order to study the effect of prolonged heating at these temperatures, other portions were dried at intervals in the oven, some for as long as two continuous weeks. Comparative figures were also obtained on air-dried and wet portions of these soils. The air drying was carried out in the shade at room temperature. The method used to sample the wet soil is described in the appended procedure.

The analytical data are discussed separately under (a) ammoniacal, (b) nitrate, and (c) the sum of the two, or total available nitrogen.

Ammoniacal Nitrogen:

Comparisons of the ammoniacal nitrogen content of the soils studied show that the air-dried portions are, in most cases, slightly lower in ammonia nitrogen than the moist, original specimens (Fig. 1 and Table I). The changes found were less than 25 pounds per acre-foot in the eight soils studied. Minor differences were also noted when the soils were heated overnight in an oven below 60° C. These soils were not completely or sufficiently dried. One sample, No. 4, decreased by 40 pounds ammonia nitrogen per acre-foot compared to the wet soil, but this ammonia was apparently nitrified and not lost, for the nitrate nitrogen increased by the same amount. When the drying period was advanced to 40 hours, there were small gains observed generally. However, samples kept in the oven at 60° C. for two weeks increased tremendously in ammonia nitrogen in every case. The gains ranged from 65 pounds to 300 pounds nitrogen per acre-foot.

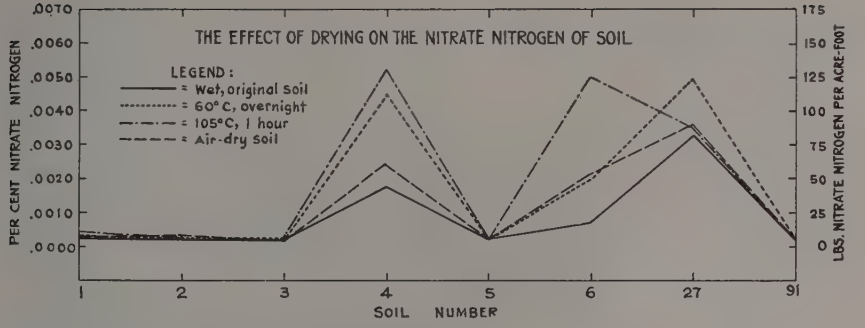

Fig. 2

On drying for one hour at 105° C., the changes in the ammoniacal nitrogen content varied from a 30-pound decrease to an increase of over 100 pounds (Soil No. 5). The decrease in the one soil (No. 4) is traceable to nitrification which also occurred at 60° C. However, when the soils were left in an oven over a weekend (about 65 hours) at the higher temperature, significant increases of 50 pounds to over 200 pounds nitrogen per acre-foot took place in every case. These figures show that an increase in temperature and also in the period of heating markedly step up the concentration of ammoniacal nitrogen in these soils. Below 60° C., where it is necessary to dry for twenty-four hours or longer, slight to over 25-pound increases of ammonia nitrogen were found. At the higher temperature of 105° C. for one hour, very great changes may thus be expected in some soils. For this reason temperatures as high as 105° C. can not be used to dry soils for the determination of field availability in ammoinacal nitrogen. Extended heating at elevated temperatures is especially to be avoided, even temperatures as low as 50° C. to 60° C. Under these conditions the factors favoring ammonification are intensified and predominate and large increases of ammonia generally prevail. Such conditions, of course, do not exist in the fields.

Nitrate Nitrogen:

The nitrate form of nitrogen is generally not affected much by temperature changes or by extended heating. In the two soils, Nos. 4 and 6 (Table II and Fig. 2), in which large increases of nitrate nitrogen do occur upon heating, it may be explained, perhaps, as due to the acceleration of the natural processes of nitrification. By subsequent re-analyses of all samples, the wet soils were found to have increased in nitrate nitrogen to the high levels reached by the samples dried by the various methods described. In soil No. 4, the gain is apparently due to nitrification of the ammoniacal nitrogen originally present in the wet soil and in No. 6, to nitrification of organic matter.

Nitrification appears to be accelerated in the early stages of heating and ammonification in the later stages.

Total Available Nitrogen:

Total available nitrogen, i.e., the sum of the ammoniacal and the nitrate forms, in naturally wet soils appeared to change only slightly, if any. Exceptions were

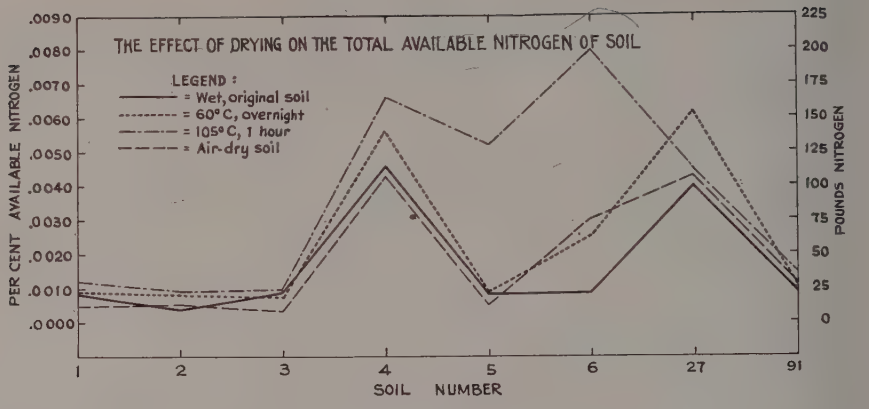

Fig. 3

found, however. In one wet soil, No. 6 (Table III and Fig. 3), the total available nitrogen increased by about 50 pounds per acre-foot when the soil was air dried. This gain is due to an increase of both the ammoniacal and nitrate forms. After standing for two weeks, this particular soil gained as much as 40 pounds nitrate nitrogen. It is further observed that this soil kept in a moist condition for a period of time increased to the same nitrogen content as the air-dried portion when both were re-analyzed later. The conclusion which may be drawn safely, we believe, is that the analysis of a soil for available nitrogen in naturally wet specimens taken from the field is quite possible and gives reasonably true and accurate results. Where an apparent exception is found, as was the case in soil No. 6, it may be due to an actual change taking place during the time required to air dry the soil.

When dried overnight in an oven at 60° C., or lower, gains up to 50 pounds nitrogen per acre-foot were found. When the soils were left over a weekend in the oven at this temperature, increases ranged up to 100 pounds nitrogen per acre-foot. Samples kept for two weeks at 60° C. gained from 65 pounds available nitrogen to over 300 pounds. At a temperature of 105° C. for one hour, these soils gained from 3 pounds to over 175 pounds nitrogen and increased from 55 pounds to over 225 pounds when incubated (dried) over a weekend at 105° C.

Drying in the oven either at 60° C. or at 105° C. increases the available nitrogen content of these soils. The increases which take place in a sizable proportion of the samples dried at 60° C. and for a short period occur in every soil tested when dried for longer periods or at higher temperatures.

Discussion

The experimental figures, although obtained from a limited number of soils which were nevertheless a representative selection, definitely support the belief that analyses of wet field samples of soils give a truer picture of the available nitrogen supply in the field at the time of sampling than either air-dried or oven-dried portions of the same soils. This brief study was not intended to learn the causes governing the relationships found to exist between nitrogen values and various methods of soil drying, but there are sufficient data presented to point toward accelerated bacterial activity and also chemical decomposition due to the

elevated temperatures employed as major causes of the increases in available nitrogen noted in the dried portions of the soils. Soils which were dried, either oven or air dried, when left standing in the dry state for a week to ten days did not change in available nitrogen as compared to their respective contents immediately after drying. (Refer to the lower figures in Tables I, II and III.) However, when the dried soils were kept moistened with distilled water for a week, the portions dried at 105° C. and also those dried at 60° C. for periods longer than 40 hours showed tremendous increases of available nitrogen. Although no attempt was made to keep the soils uncontaminated, those kept at 105° C. for 60 hours are apparently only partially sterilized. On the addition of moisture, the bacteria which produce ammonia increased to the greatest extent in the soils kept at the highest temperature and for the longer period. This is shown (Table I, upper figures) in the ammonia content of the soils. The organisms detrimental to the nitrifying bacteria were not affected or destroyed when heated below 60° C. overnight.

The soils selected for this test included those extremely difficult to dry. The wet sampling method proposed is admittedly difficult to employ on these soils, but when these same soils were dried, by whichever means selected, the subsequent handling of the dry specimens was much more difficult and consumed more time than the method suggested. This is due to the fact that the soils in question caked into a solid, rocky mass when dried.

The laboratory sampling method used, and which is recommended for handling moist or wet field soils, is as follows:

1. If the sample taken from the field is large, spread the soil out on a wide sheet of heavy paper.

2. Break up the large masses into smaller pieces with a trowel.

3. Start from one end of the sheet and quarter by spading off a quarter of each large mass of soil and also taking one-fourth of the smaller pieces.

4. Break up the sample further and repeat Step 3 until one to two pounds are obtained.

5. Spread the sample on a square, 8-mesh wire screen (8 mesh to a linear inch) about 18 inches to a side. Press the soil with a large wooden mallet. (The screen should be made so that the wire bottom rests about three inches above the table, the screen height being about two inches or more.)

6. Press a portion of *each* part of the sample through the screen until about a tumblerful is obtained. (It is not necessary to press all of the soil through the screen.)

7. Mix by means of a spatula.

8. Fill the 10-gram soil cup by taking a small portion of soil from various parts of the mound, pack the cup solidly and level it.

9. Remove excess soil from spatula and cup.

10. Transfer the contents of the cup to a 250-ml. beaker by digging out neatly with the cleaned spatula.

11. Add 50 ml. Reagent 5 N and stir well, using two stirring rods held together in one hand if necessary.

12. Filter through a dry filter into a 100-ml. beaker and proceed with the usual R.C.M. ammoniacal and nitrate nitrogen determinations on the filtrate.

TABLE I

PER CENT AMMONIACAL NITROGEN

Lab. No.	Description of samples	Specimens analyzed	Treatments: Air-dry soil	Wet orig. fld. soil	Below 60° C.: Over-night	40 hrs.	2 wks.	105° C.: 1 hr.	60 hrs.
1	Honolulu Plantation Co., near poi factory	Immediately after treatment	.0002	.0006	.0006	.0007	.0050	.0008	.0028
		After 2 weeks	.0002	.0002	.0002	.0006	.....	.0006	.....
2	Expt. Stn. Seedling Station, Ewa	Immediately after treatment	.0002	.0002	.0006	.0009	.0028	.0007	.0026
		After 2 weeks	.0002	.0002	.0003	.0007	.....	.0006	.....
3	Waialua Agric. Co., Ltd., Mokuleia side	Immediately after treatment	.0002	.0007	.0006	.0008	.0056	.0007	.0028
		After 2 weeks	.0004	.0002	.0006	.0006	.....	.0007	.....
4	Waialua Agric. Co., Ltd., valley soil	Immediately after treatment	.0019	.0028	.0011	.0020	.0150	.0016	+.0100
		After 2 weeks	.0021	.0002	.0011	.0018	.....	.0018	.....
5	Kahuku Plantation Co., Waialua side	Immediately after treatment	.0003	.0006	.0006	.0007	.0005	+.0050	.0030
		After 2 weeks	.0002	.0002	.0003	.0006	.....	.0050	.....
6	Kahuku Plantation Co., Punaluu	Immediately after treatment	.0008	.0002	.0006	.0012	+.0100	.0030	+.0050
		After 2 weeks	.0006	.0002	.0003	.0010	.....	.0024	.....
27	Olaa Sugar Co., Ltd. Field 4–5	Immediately after treatment	.0007	.0007	.0012	.....	.....	.0010	+.0050
		After 2 weeks	.0012	.....	.0011	.....	.....	.0010	.0040*
91	Manoa Substation, surface, Mauka of D–3	Immediately after treatment	.0009	.0007	.0010	.....	.....	.0012	+.0100
		After 2 weeks	.....	.....	.0008	.....	.....	.0011	.....

* Dried on hot plate for 10 hours.

Plus sign (+) denotes quantity more than that indicated.

TABLE II

PER CENT NITRATE NITROGEN

Lab. No.	Description of samples	Specimens analyzed	Treatments: Air-dry soil	Wet orig. fld. soil	Below 60° C.: Over-night	Below 60° C.: 40 hrs.	Below 60° C.: 2 wks.	105° C.: 1 hr.	105° C.: 60 hrs.
1	Honolulu Plantation Co., near poi factory	Immediately after treatment	.0003	.0002	.0003	.0005	.0003	.0004	.0002
		After 2 weeks	.....	.0005	.0002	.0002	.....	.0002	.0002
2	Expt. Stn. Seedling Station, Ewa	Immediately after treatment	.0003	.0002	.0002	.0002	.0002	.0002	.0002
		After 2 weeks	.....	.0005	.0002	.0002	.....	.0002	.0002
3	Waialua Agric. Co., Ltd., Mokuleia side	Immediately after treatment	.0002	.0002	.0002	.0002	.0003	.0003	.0002
		After 2 weeks	.....	.0003	.0002	.0002	.....	.0002	.0002
4	Waialua Agric. Co., Ltd., valley soil	Immediately after treatment	.0024	.0018	.0045	.0040	.0020	+.0050	.0028
		After 2 weeks	.....	.0050	.0040	.0045	.....	.0040	.0028
5	Kahuku Plantation Co., Waialua side	Immediately after treatment	.0002	.0002	.0003	.0003	.0003	.0003	.0002
		After 2 weeks	.....	.0002	.0002	.0002	.....	.0003	.0002
6	Kahuku Plantation Co., Punaluu	Immediately after treatment	.0022	.0007	.0017	.0035	.0030	+.0050	.0030
		After 2 weeks	.....	.0022	.0020	.0031	.....	.....	.0030
27	Olaa Sugar Co., Ltd. Field 4–5	Immediately after treatment	.0036	.0033	.0050	.....	.....	.0035	.0038
		After 2 weeks	.....	.....	.0045	.....	.....	.0033	.0025*
91	Manoa Substation, surface, Mauka of D–3	Immediately after treatment	.0002	.0002	.0002	.....	.....	.0002	.....
		After 2 weeks	.....	.....	.0002	.....	.....	.0002	.0002

* Dried on hot plate for 10 hours.

Plus sign (+) denotes quantity more than that indicated.

TABLE III

PER CENT TOTAL AVAILABLE NITROGEN

Lab. No.	Description of samples	Specimens analyzed	Treatments: Air-dry soil	Wet orig. fld. soil	Below 60° C.: Over-night	Below 60° C.: 40 hrs.	Below 60° C.: 2 wks.	105° C.: 1 hr.	105° C.: 60 hrs.
1	Honolulu Plantation Co., near poi factory	Immediately after treatment	.0005	.0008	.0009	.0012	.0053	.0012	.0030
		After 2 weeks	.0005	.0007	.0004	.0008	.....	.0008	.0026
		Water added after heating	.....	.0008	.....	.0027	.....	.0042	.0072
2	Expt. Stn. Seedling Station, Ewa	Immediately after treatment	.0005	.0004	.0008	.0011	.0030	.0009	.0028
		After 2 weeks	.0004	.0007	.0005	.0009	.....	.0008	.0023
		Water added after heating	.....	.0010	.....	.0028	.....	.0042	.0102
3	Waialua Agric. Co., Ltd., Mokuleia side	Immediately after treatment	.0004	.0009	.0008	.0010	.0059	.0010	.0030
		After 2 weeks	.0006	.0005	.0008	.0008	.....	.0009	.0024
		Water added after heating	.....	.0022	.....	.0042	.....	.0062	.0102
4	Waialua Agric. Co., Ltd., valley soil	Immediately after treatment	.0043	.0046	.0056	.0060	+.0170	+.0066	+.0130
		After 2 weeks	.0044	.0052	.0051	.0063	.....	.0058	+.0130
		Water added after heating	.....	.0052	.....	.0105	.....	.0105	.0122
5	Kahuku Plantation Co., Waialua side	Immediately after treatment	.0005	.0008	.0009	.0010	.0053	+.0053	.0032
		After 2 weeks	.0004	.0004	.0005	.0008	.....	.0053	.0028
		Water added after heating	.....	.0015	.....	.0040	.....	.0108	.0082
6	Kahuku Plantation Co., Punaluu	Immediately after treatment	.0030	.0009	.0025	.0047	+.0130	+.0080	+.0080
		After 2 weeks	.0024	.0024	.0023	.0041	.....	.....	.0064
		Water added after heating	.....	.0016	.....	.0058	.....	.0085	.0082
27	Olaa Sugar Co., Ltd. Field 4–5	Immediately after treatment	.0043	.0040	.0062	.....	.....	.0045	.0086
		After 2 weeks	.0052	.....	.0056	.....	.....	.0043	.0065
91	Manoa Substation, surface, Field 7	Immediately after treatment	.0011	.0009	.0012	.....	.....	.0014	+.0100
		After 2 weeks	.....	.....	.0010	.....	.....	.0013	+.0100

Plus sign (+) denotes quantity greater than that indicated.

Since the soil cup is packed solidly, the regular R.C.M. tables giving ammoniacal and nitrate nitrogen values may be used, and correctly so, without further change.

The wire screen is washed and brushed and the excess water shaken off. It is then ready for use again without further drying.

Conclusions

A method for sampling moist field soils is proposed whereby reproducible analytical figures of available nitrogen (ammoniacal and nitrate) are obtainable quickly by means of rapid chemical methods. Such figures, based on the analysis of the original wet field soils are believed to be not only more representative of the actual condition of the field soil at the time of sampling, but are obtainable much more quickly and also more easily than when procedures are followed based upon regulation dried soil specimens.

Air drying or drying in the oven at 60° C. or 100° C., even for short periods, changed the available nitrogen content of soils to a great extent in most cases. From the available soil nitrogen viewpoint, the least objectionable method of soil drying is air drying.

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Sunlight-Nitrogen Relationships

By R. J. Borden

An abundance of sunlight and an adequate supply of available nitrogen are known to be prime assets for successful sugar production. Many of our field experiments have given results which attest to the effect of nitrogen upon both cane yields and its quality. Much less is actually known about the effects of sunlight or of the interaction of these two factors—sunlight and nitrogen. Consequently a skirmish test* was undertaken to see what indication of this important relationship could be secured. The results of this preliminary test are now available (Table V), and although they are undoubtedly quite far from the complete answer, they are considered sufficiently interesting to present herewith for the discussion they may evoke and to stimulate still further investigation.

The Plan

To provide conditions that would be comparable and capable of being easily handled, the equipment of the Mitscherlich department was used. Seventy-two Mitscherlich pots were filled with identical amounts of thoroughly mixed Makiki soil, similarly fertilized with phosphate and potash, each planted with two uniform shoots of cane, and all given adequate irrigation without loss of drainage water during the whole period of growth. These pots were placed on flatcars which were run into the greenhouse during inclement weather and at night. To provide for the sunlight differentials that were introduced, one of the glass-roofed sheds was lined (roof and sides) with a single layer of natural burlap which provided a compartment in which the plants could be given a considerably reduced amount of direct sunlight; this was estimated by a Weston photronic exposure meter to be less than 5 per cent of the intensity of direct sunlight outside.

Two cane varieties were used: 31-1389 which starts off fast and grows very rapidly during its early life, and H 109 which starts more slowly and makes its greatest growth at a somewhat later stage.

The Variables

Four "sunlight" variables were introduced during the latter part of the growing period while millable stalk was being formed. These may be identified as follows:

Treatment A—The controls. These plants were grown in all available direct sunlight from time of starting the crop on January 11, 1938 until it was harvested on March 29, 1939.

Treatment B—Decreased light *after* the "boom stage." These plants had all possible direct sunlight for the first 10 months (until November 30); thereafter for the four months from December 1 to March 28, they were given direct sunlight each morning only, being placed in the shaded house at noon each day.

* Experiment Station, H.S.P.A., Project A–105—No. 118.

Treatment C—Decreased light *during* the "boom stage." These plants had all available direct sunlight for their first 6 months (until July 31); thereafter during the alternate months of August, October, December, and February, they received direct sunlight each morning only; during September, November, January, and March they again received all possible direct sunlight.

Treatment D—Intermittent light *variation after* the "boom stage." Like Treatment B, these plants received direct sunlight daily for the first 10 months; thereafter they were left in the shaded house all day on Friday, Saturday, and Sunday of each week until harvested. They received full sunlight on other week days during this period.

Three nitrogen variables were included. The total amounts were divided into monthly applications and supplied during the first 9 months of growth:

Treatment I supplied each pot with a total of 5 grams of N which was considered an inadequate supply for a maximum yield.

Treatment II supplied the crop with 8.5 grams of N during the same period; this has been our standard practice for growing a good crop of cane in a Mitscherlich pot.

Treatment III furnished a total of 15.5 grams of nitrogen for the crop; this was undoubtedly more than could be efficiently used during the 14-month growing period.

Observations During Growth Period

Certain pertinent observations were made after the differentials had been imposed:

(1) There were very few live "tillers" in the pots which received an inadequate supply of nitrogen (I); although many suckers had started to grow in these pots, their early mortality had been exceptionally heavy.

(2) An abundant and very vigorous sucker growth occurred in the pots which had received excessive nitrogen applications (III); similarly many of the upper eyes on the stalks had started to grow. (Treatment II was intermediate with I and III in its extent and character of tillering.)

(3) Particularly striking was the effect of Treatment C upon the length of the internodes which were formed under its condition of reduced sunlight during August and October. These internodes were 2 to 3 times longer than respective internode growth made by the other plants which were in full sunlight during this period (Fig. 1). This effect of reduced light in increasing the internode elongation was not as prominent after December.

(4) The internodes formed after December were distinctly shorter in the "controls" (Treatment A) than in plants which had not received the maximum of sunlight. However, the total number of millable joints was found to be slightly greater in these "controls." Counts made shortly before harvest show the average number of dry-leaf millable joints for the nitrogen differentials to be quite similar, but for the sunlight differentials we have the following comparisons:

Treatment A—stalks average 36 dry-leaf joints
Treatment B—stalks average 33 dry-leaf joints
Treatment C—stalks average 31 dry-leaf joints
Treatment D—stalks average 30 dry-leaf joints

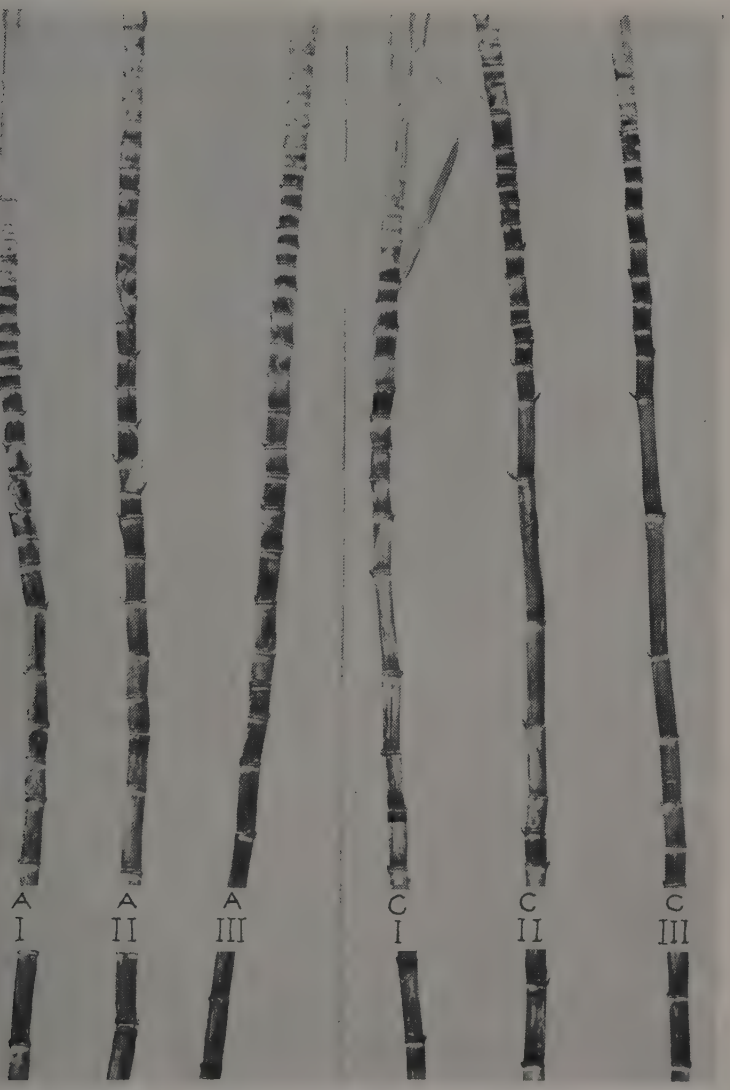

Fig. 1. Typical H 109 stalks showing the effects of reduced sunlight on elongation of internodes.

A—Control—grown in full sunlight.
C—Reduced light during the 7th, 9th, 11th, and 13th months.
I—Supplied with inadequate nitrogen.
II—Supplied with adequate nitrogen.
III—Supplied with an excess of nitrogen.

General Effects

The cane was harvested at the age of 14 months. The data which were secured have been studied by analysis of variance to determine the significance of both of the main effects (nitrogen and sunlight) and of their interaction—separately for both varieties. Briefly this analysis may be summarized as follows:

Measurement	Variety	Effect of sunlight	Effect of nitrogen	Interaction of sunlight and nitrogen
Total dry weight	31-1389	Not significant	Significant	Not significant
Total dry weight	H 109	Significant	Significant	Not significant
Trash and tops only	31-1389	Not significant	Significant	Not significant
Trash and tops only	H 109	Not significant	Significant	Not significant
Millable cane	31-1389	Significant	Significant	Not significant
Millable cane	H 109	Not significant	Significant	Not significant
Quality ratio	31-1389	Significant	Significant	Not significant
Quality ratio	H 109	Not significant	Significant	Not significant
Sugar	31-1389	Significant	Significant	Not significant
Sugar	H 109	Not significant	Not significant	Not significant

From this summary we would be forced to conclude (*a*) that the response to length and period of direct sunlight exposure as given to these plants had been somewhat different for the two varieties; (*b*) that the generally expected effect of nitrogen had again been demonstrated; and (*c*) that there was no reliable indication of any interaction between sunlight and nitrogen, i.e., of any differential response to the nitrogen variables used with the several periods of direct and subdued sunlight conditions as they were imposed in this investigation.

Sunlight Effects

More specifically, when we examine the significant data from Table I we note that the variety H 109 produced definitely more total dry matter when it was grown continuously in full sunlight, but that the reduced sunlight differences had no reliable effect upon its production of millable cane or its quality and final sugar yield. On the other hand, there was a pronounced tendency for the variety 31-1389 to make more millable cane and sugar when its exposure to direct sunlight had been somewhat restricted. Apparently also, a somewhat better cane quality was obtained from Treatment C in which the reduced sunlight was effective during the "boom stage."

TABLE I

EFFECTS OF VARIATIONS IN SUNLIGHT

(Averages from 9 Pots)

Sunlight treatments	Dry yield* per pot (gms.)		Dry weight of trash and tops only (gms.)		Wgt. millable cane per pot (lb)		Q.R.		lb sugar	
	31-1389	H 109	31-1389	H 109	31-1389	H 109	31-1389	H 109	31-1389	H 109
A.....	1205	1320	483	523	3.86	3.77	7.10	6.78	.55	.56
B.....	1245	1209	483	499	4.47	3.48	7.50	6.91	.60	.51
C.....	1224	1240	453	491	4.54	3.83	6.84	6.56	.66	.58
D.....	1215	1202	472	491	4.55	3.54	7.31	6.73	.63	.53
Amount of difference needed for significance ..	62	73	41	38	.51	.57	.26	.31	.07	.09

* Includes all trash, bagasse, solids in juice, and non-millable tops and leaves.

Nitrogen Effects

The data in Table II show that significantly lower total dry weights were secured from both varieties with the lowest amount of nitrogen supplied (Treatment I), and that there was no reliable increase for the excessive nitrogen application (III) over a moderate supply (II). A very definite increase in the amount of trash and cane tops was the result of increased nitrogen applications on both varieties.

With respect to the millable cane, the answer was different for the two varieties: the excess nitrogen application produced less millable 31-1389 cane than the lowest amount; but for best yields from H 109 the low amount was wholly inadequate.

The deleterious effect of increased nitrogen on cane quality is nicely shown: the heavy nitrogen applications (III) gave a cane with definitely poorer quality than the medium or low amounts.

TABLE II

EFFECT OF DIFFERENT AMOUNTS OF NITROGEN
(Average of 12 Pots)

Nitrogen treatments	Dry yield per pot (gms.)		Dry weight of trash and tops only (gms.)		Weight millable cane per pot (lb)		Q.R.		lb sugar	
	31-1389	H 109	31-1389	H 109	31-1389	H 109	31-1389	H 109	31-1389	H 109
I.....	1127	1126	539	595	4.51	3.22	6.95	6.40	.65	.51
II.....	1253	1288	633	691	4.55	3.91	6.92	6.73	.66	.58
III.....	1286	1314	719	717	4.01	3.83	7.68	7.11	.52	.54
Amount of difference needed for significance ..	54	63	35	17	.44	.50	.24	.27	.06	.08

The final sugar yield from 31-1389 shows both the low and medium nitrogen applications to be superior to the high amount. With H 109, the sugar yields are not significantly different for the 3 nitrogen treatments and present-day economics would therefore indicate a preference for the lower amount.

Trash

A study of that percentage of the total dry weight which was made up by the trash and tops, shows that the variety 31-1389 was influenced to a greater extent than H 109, being affected more especially by the increases in nitrogen than by the variations in sunlight. Our earlier observations had indicated that the higher amount of nitrogen was producing a very abundant and vigorous sucker growth, which had not formed millable cane when the crop was harvested at the age of 14 months (Fig. 2). The variations in light were probably without definite effect on this trash: dry weight ratio with H 109 cane, but with 31-1389 we have, by inference, an indication that when the periods of reduced light had occurred all through the "boom stage" (Treatment C) the plants were more efficient in making millable stalk.

DRY WEIGHT OF TRASH AND TOPS AS PER CENT OF TOTAL DRY WEIGHT

Sunlight treatment	31-1389	H 109	Nitrogen treatment	31-1389	H 109
A.....	53.4	52.8	I.....	47.8	52.9
B.....	51.7	52.3	II.....	50.5	53.6
C.....	49.4	52.8	III.....	55.9	54.6
D.....	51.7	54.5			

Fig. 2. Showing the effect of increased nitrogen applications upon the sucker growth. *I*—Inadequate Nitrogen; *II*—Adequate Nitrogen; *III*—Excess Nitrogen.

Nitrogen Content

The percentage of nitrogen in the active green leaves at harvest may be related in some manner to the foregoing observations. The data in Table III show a higher percentage of total nitrogen in the leaves of plants which had received the larger nitrogen applications; this was especially so for the young sucker growth even though the greater part of this growth had been made after the last application of nitrogen, five months before harvesting.

TABLE III

PER CENT TOTAL NITROGEN IN ACTIVE CANE LEAVES AT HARVEST

Variety	Sunlight treatment	Leaf sample* from	Nitrogen treatments I		II		III		Sunlight treatment averages	
31-1389	A	Primary stalks	.85		1.13		1.58		.92	
		Suckers		.86		1.03		1.68		1.19
	B	Primary stalks	1.05		1.28		1.56		1.30	
		Suckers		n.s.		1.11		1.40		1.26
	C	Primary stalks	.99		1.20		1.35		1.18	
		Suckers		.73		1.05		1.56		1.11
	D	Primary stalks	.96		1.28		1.44		1.23	
		Suckers		n.s.		1.29		1.80		1.55
Nitrogen averages:		Primaries	.96		1.22		1.23			
Nitrogen averages:		Suckers		.80		1.12		1.61		
H 109	A	Primary stalks	.90		1.07		1.69		1.22	
		Suckers		.80		.99		1.56		1.12
	B	Primary stalks	1.20		1.35		1.46		1.34	
		Suckers		1.04		1.20		1.54		1.26
	C	Primary stalks	.85		1.12		1.44		1.14	
		Suckers		n.s.		1.28		1.70		1.49
	D	Primary stalks	1.06		1.44		....		1.25	
		Suckers		.93		1.54		1.80		1.42
Nitrogen averages:		Primaries	1.00		1.25		1.53			
Nitrogen averages:		Suckers		.92		1.25		1.65		

* Analysis from single leaf-punch sample only, but all stalks "punched" for same.
n.s. = no sample.

The effect of variations in light upon the nitrogen content of the leaves of H 109 is perhaps not a significant one, but there is an indication that with 31-1389, the nitrogen applied had been more completely used in those plants which had been grown under the most abundant sunlight conditions. And this indication appears to be supported in a general way by the fact that the greater percentages of nitrogen in the primary stalks occur in Treatments B and D which did not get the full benefit of the sun during their last four months of growth.

The percentage of nitrogen in the crusher juice of both varieties was not affected significantly by the sunlight variations, but the increased nitrogen applications quite definitely increased the nitrogen content of this juice (Table IV).

TABLE IV

EFFECT OF SUNLIGHT AND NITROGEN ON THE PER CENT NITROGEN OF CRUSHER JUICE

Per cent nitrogen in crusher juice (averages of 3 pots)

Treatments	31-1389 I	31-1389 II	31-1389 III	H 109 I	H 109 II	H 109 III
A	.033	.046	.158	.029	.036	.051
B	.035	.061	.139	.034	.038	.095
C	.029	.063	.148	.030	.038	.078
D	.038	.050	.130	.033	.040	.082

Amount of difference needed for significance between the nitrogen treatment averages: for 31-1389 = .023; for H 109 = .023.

Nitrogen Content and Cane Quality

The harvest data indicate a rather broad, general relationship between the nitrogen content of either the leaf or the crusher juice, and the cane quality, i.e., when the treatment was such that it definitely increased the percentage nitrogen in the plant, a poorer quality resulted. This may be shown very nicely if we disregard the treatment differentials and use the complete set of data to determine the correlation and regression coefficients for nitrogen and quality ratio. Positive significant correlations have been obtained, as will be seen from the following:

Coefficient	Variety 31-1389	Variety H 109
1. Correlation (r), i.e.,		
Percentage relation between		
(a) Q.R. and % N in leaf	$r = .72 \mp .14$	$r = .76 \mp .13$
(b) Q.R. and % N in juice	$r = .65 \mp .10$	$r = .63 \mp .10$
2. Regression, i.e.,		
Estimate of Q.R.		
(a) from % N in leaf	$Q.R. = 5.56 + 1.35 \times \%\ N$	$Q.R. = 5.54 + .94 \times \%\ N$
(b) from % N in juice	$Q.R. = 6.69 + 6.57 \times \%\ N$	$Q.R. = 6.41 + 14.11 \times \%\ N$

TABLE V

DETAILED HARVEST RESULTS
(Averages of 3 pots, except as noted)

Variety	Treatment	Total dry weight (gms.)	Dry weight of trash and tops only (gms.)	Millable cane (lb)	Q.R.	Sugar (lb)	% total nitrogen in juice	% total nitrogen in leaves* of primary stalks	% total nitrogen in leaves* of suckers
31-1389	A I	1072	553	3.82	7.1	.54	.033	.85	.86
	II	1260	654	4.00	6.6	.61	.046	1.13	1.03
	III	1283	724	3.77	7.6	.50	.158	1.58	1.68
	B I	1136	546	4.58	7.1	.65	.035	1.05	n.s.
	II	1267	650	4.75	7.3	.65	.061	1.28	1.11
	III	1333	735	4.08	8.0	.51	.139	1.56	1.40
	C I	1166	527	4.87	6.5	.72	.029	.99	.73
	II	1232	600	4.55	6.7	.68	.063	1.20	1.05
	III	1273	686	4.20	7.3	.57	.148	1.35	1.56
	D I	1136	529	4.77	7.1	.68	.038	.96	n.s.
	II	1251	627	4.91	7.1	.69	.050	1.28	1.29
	III	1256	730	3.97	7.7	.52	.130	1.44	1.80
H 109	A I	1168	643	2.93	6.3	.46	.029	.90	.80
	II	1319	702	3.95	6.8	.57	.036	1.07	.99
	III	1472	747	4.44	7.0	.63	.051	1.69	1.56
	B I	1019	552	2.51	6.5	.39	.034	1.20	1.04
	II	1293	705	4.15	6.9	.60	.038	1.35	1.20
	III	1314	738	3.78	7.3	.53	.095	1.46	1.54
	C I	1177	598	3.88	6.3	.61	.030	.85	n.s.
	II	1313	680	3.98	6.5	.61	.038	1.12	1.28
	III	1230	686	3.63	6.8	.53	.078	1.44	1.70
	D I	1138	589	3.57	6.3	.56	.033	1.06	.93
	II	1229	678	3.57	6.7	.54	.040	1.44	1.54
	III	1240	692	3.47	7.2	.48	.082	....	1.80

* Simple composite sample only.

Conclusions

1. The two cane varieties 31-1389 and H 109 responded somewhat differently to variations in exposure to direct sunlight. The effects were generally more significant upon 31-1389.

2. The commonly accepted opinions concerning the various effects of nitrogen on cane growth and composition were quite nicely verified.

3. Considered in the light of the technique that was used in this skirmish test, we were unable to show any significant interaction between sunlight and nitrogen.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 16, 1939 TO JUNE 14, 1939

Date	Per pound	Per ton	Remarks
Mar. 16, 1939..	2.85¢	$57.00	Puerto Ricos.
" 18.....	2.84	56.80	Puerto Ricos, 2.83; Philippines, 2.85.
" 20.....	2.85	57.00	Cubas.
" 21.....	2.87	57.40	Philippines.
" 28.....	2.86	57.20	Philippines, Puerto Ricos.
" 29.....	2.88	57.60	Puerto Ricos.
Apr. 5.....	2.90	58.00	Puerto Ricos, Philippines.
" 12.....	2.88	57.60	Cubas.
" 13.....	2.92	58.40	Philippines, Puerto Ricos.
" 14.....	2.935	58.70	Cubas, 2.95; Puerto Ricos, 2.92.
" 18.....	2.95	59.00	Puerto Ricos.
" 21.....	2.93	58.60	Cubas.
" 28.....	2.89	57.80	Cubas.
May 8.....	2.925	58.50	Puerto Ricos, 2.92; Philippines, 2.93.
" 9.....	2.915	58.30	Puerto Ricos, 2.93; Cubas, 2.90.
" 10.....	2.94	58.80	Philippines.
" 11.....	2.95	59.00	Philippines.
" 16.....	2.90	58.00	Cubas.
June 2.....	2.86	57.20	Philippines.
" 6.....	2.87	57.40	Puerto Ricos.
" 8.....	2.85	57.00	Cubas.
" 14.....	2.80	56.00	Puerto Ricos.

THE HAWAIIAN PLANTERS' RECORD

EXPERIMENT STATION STAFF

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R. C. L. Perkins, Consulting Entomologist
O. H. Swezey, Consulting Entomologist
F. X. Williams, Associate Entomologist
R. H. Van Zwaluwenburg, Associate Entomologist
F. A. Bianchi, Assistant Entomologist
J. S. Rosa, Laboratory Technician

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A. Doi, Field Assistant
R. Urata, Field Assistant

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P. E. Chu, Assistant Chemist
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Colin Potter, Nursery Superintendent

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A. R. Lamb, Research Associate
Howard Cooper, Research Assistant
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